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SECOND EDITION

REVISED AND LARGELY RE-WRITTEN BY

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[illegible] LECTURER IN METALLURGY, UNIVERSITY OF BIRMINGHAM,
SECRETARY, STAFFORDSHIRE IRON AND STEEL INSTITUTE.

FIRST EDITION WRITTEN BY

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AUTHOR OF "CADMIUM: ITS METALLURGY, PROPERTIES AND USES."

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Dedicated

TO

PROFESSOR THOMAS TURNER,

AS A TOKEN OF RESPECT AND ADMIRATION.

PREFACE TO SECOND EDITION.

THIRTEEN years have elapsed since the publication of the first edition of this book. During this interval new designs of spraying apparatus have been evolved using wire, powder and molten metal. Many fresh applications have also been successfully exploited, some of which are becoming of great importance to the works engineer, as, for instance, in the building up of worn machinery ; but apart from these, metal spraying demands increasing consideration as a means of combating corrosion. The corrosion of mild steel occurs irrespective of its composition, and the austenitic stainless steels are too expensive for any but special environments where corrosion is very severe. At the present time one of the most common methods of protecting iron and steel is painting, but research is showing that this method is only really effective when the surface of the steel is prepared or cleaned by costly treatments, such as sand blasting. This treatment is the first stage in the metal spraying process and if one is prepared to do this, a coat of sprayed zinc or aluminium makes the ideal protective coating for steel which will later be exposed to the weather ; circumstances will decide as to whether or not subsequent coats of paint are applied to the deposit, which would act as an excellent key to the paint.

Details of much of the apparatus which was considered modern at the time of the first edition of the book have been relegated to Chapter II, which also contains new details of the development of pistols spraying powder and molten metal, and of electric pistols. Except for a few pages, Chapters III and IV contain entirely new data, and the reviser considers the sections on the health of the worker and the effect of variables in sand blasting to be particularly useful additions.

During the last five years, considerable research has been carried out on the nature of the sprayed metal, and this has necessitated doubling the length of Chapter V, which deals with this subject, and which also contains an outline of the electrochemical nature of corrosion phenomena.

On the other hand, little alteration has been made to Chapter VI. Many new applications are discussed in Chapter VII and a section on building-up work is added in view of the increasing importance of this subject. The Bibliography has been brought up to date.

The reviser's interest in metal spraying is purely scientific and he is particularly indebted to three competing firms for supplying samples of their products for independent tests. Facilities have been freely given and blocks lent by Messrs. Metallisation, Ltd., Mellowes & Co., Ltd., Schori Metallising Process, Ltd., and Lovick Johnson Co. The reviser acknowledges with gratitude the help received from Messrs. W. E. Ballard, A. E. Phipps, C. F. Lumb, J. C. Bowen, J. Barrington-Stiles, A.M.I.Mech.E., F. W. Neville, T. H. Turner, H. E. Collier, M.B., Ch.B., T. H. Murray-Watson, and D. E. W. Harris.

Certain of the illustrations have been reproduced from the *Journal of the Institute of Metals*, *Metal Treatment* and *Metallurgia*. Blocks have been loaned also by Messrs. The British Oxygen Co., Ltd., A. C. Cossor, Ltd., Electric Resistance Furnace Co., Ltd., Equipments, Ltd., Murex Welding Processes, Ltd., and Tilghman's Patent Sand Blast Co., Ltd.

E. C. R.

DEPARTMENT OF METALLURGY,
UNIVERSITY OF BIRMINGHAM.
November, 1938.

PREFACE TO FIRST EDITION.

A METHOD of coating even such large structures as storage tanks, ships, bridges and railway stations with a uniform adherent layer of almost any desired metal is of tremendous economic importance. Every engineer has to combat corrosion by liquids, or oxidation at high temperature. Metal spraying is no certain panacea for these troubles, but it has been used with such success that all metallurgists, chemists and engineers should be informed of its capabilities. Many processes of metallisation have been invented, and are in use at the present day, but only the metal-spray process is capable of practical work upon large finished structures. Its capabilities do not, however, end there, for it enables one to apply coatings of almost any metal upon the surface of any desired object, be it fabric, wood, masonry or metal. Herein lie great possibilities for the employment of this process in artistic work, a field in which it has made great strides in certain Continental countries. In the present book the authors have endeavoured to collect from the literature upon this subject and from their own experimental work such information as will enable engineers, metallurgists and other technologists to form a judgment of the value of the metal-spray process. The authors have had special facilities for the study of the subject in this and other countries, but their interest in the process is purely scientific, as they are not connected with any firm operating it commercially. They wish to acknowledge their indebtedness to the inventor and others who have given them information or permitted them to visit their works. It is hoped that reference to the sources of information will in all cases be found in the text. They consider that the metal spraying process merits greater attention in this country than it has hitherto received, and that it will be increasingly employed in our home industries.

T. H. T.
N. F. B.

1926.

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METAL SPRAYING

CHAPTER I.

EARLY ATTEMPTS AT METAL SPRAYING.

As this is the first book in English upon Metal Spraying, it is well to point out that this modern method of metallisation is due largely to the development of certain inventions made by Dr. M. U. Schoop of Zürich. About 1911 he conceived the idea of coating objects by means of a spray of fine metallic particles, and to develop this idea, which he alone appears to have appreciated at its full value, he employed successively, Herkenrath, Bauerlin, Matzinger, and, among others, his elder son Werner Schoop. Many of the mechanical contrivances which have brought the process to its present perfection have been due in no small measure to such workers. More recently Jung and Schori, to mention but two others, have added to the practical utility of the process.

Like many other inventors, Dr. Schoop failed to make himself universally popular ; perhaps if he had let others carry out the commercial development of the process he might have been happier in this respect. The fact cannot be overlooked, however, that the process has been for many years known as "The Schoop Process," and that he has continued to maintain an interest in its use.

In the early days of the process it was boomed immoderately, and, of course, proved to have many faults when exploited commercially. This unfortunate beginning in England was due partly to the fact that the invention was of foreign origin, and partly also to the fact that the few Englishmen who had any knowledge of it were called away on war service. Until after the War the process remained practically unknown so far as this country was concerned, but it achieved a considerable degree of success in a number of foreign countries.

For very much of the historical matter contained in the first two chapters of the book, the authors have to thank the inventor for verbal and written information supplied to them, and also for his permission to use such illustrations as have been taken from his early publications.

Metal Spraying, as distinct from Metallisation, has been practised in many forms. The production of metallic powders for use in paints, in "bronzing," or even in such specialities as storage-battery plates, has been the incentive to much thought and experiment. The manufacture of powdered metal by pulverising cold metals or alloys is naturally expensive ; a characteristic of such materials being their strength and resistance to disintegration by mechanical forces. It was a move in the right direction, therefore, when attempts were made to produce metal powders from *molten* *metal,* because that requires far less energy for its pulverisation. Two distinct methods of so treating molten metals have been tried—*gaseous* and *mechanical.*

A somewhat crude attempt to solve the problem with the use of a gaseous blast is illustrated in fig. 1.

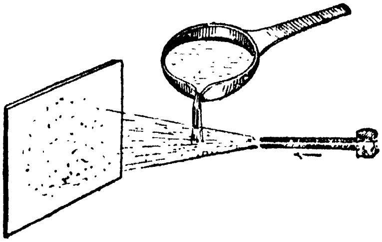

Fig. 1.—Primitive Method of Pulverising Molten Metal.

This represents a method, patented in 1882 in Germany, by which it was hoped to produce lead powders for accumulators. The inventor realised that one could either collect the powder and press it into the desired form of porous plate or project it against some fixed surface from which it may or may not be separated. No one appears to have regarded the coatings so produced as an end in themselves, but only as a step in the manufacture of accumulators.

Ten years later a method was introduced for spraying easily fusible metals. Fig. 2 illustrates this diagrammatically. It suffered from the practical disadvantage that it was difficult, although not impossible, to suck up so heavy a metal as lead by means of the heated blast passing over the nozzle which was held in the molten metal.

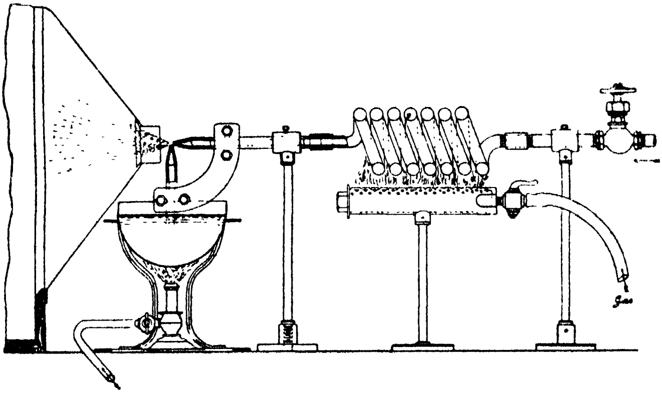

Fig. 2.—Metal Pulveriser, in which Molten Metal is Sucked up by a Jet by the action of the Blast.

The inventor, indeed, appears to have realised this, for another more practicable apparatus was also described. The principle upon which this operated may be gathered from fig. 3. Molten metal flows by gravity to the nozzle and is pulverised by a steam blast which has been superheated in passing through the molten metal in a pipe from the far side of the melting-pot.

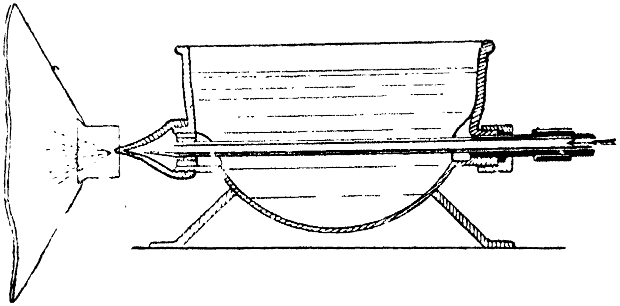

FIG. 3.—Apparatus in which Gravity-fed Molten Metal is Pulverised by Superheated Steam.

This apparatus, though practicable, was improved upon a few years later, as shown in fig. 4.

Here we see that the heating of the blast has been accomplished outside the melting-pot in a special coil. The older method had made possible

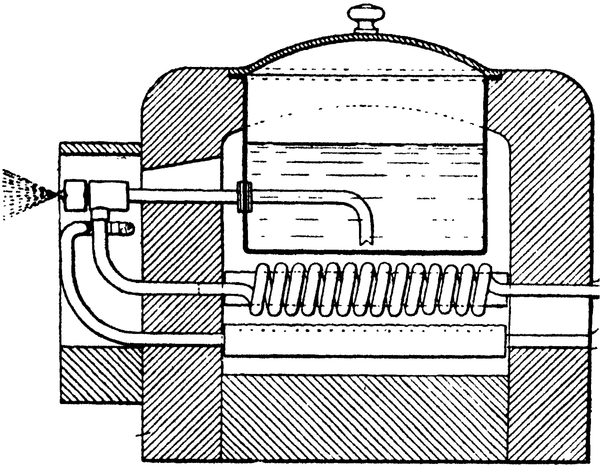

FIG. 4.—Molten Metal Sprayer with Annular Blast Nozzle.

a serious explosion should corrosion of the pipe or other defect permit moisture to come into contact with the molten metal. Fracture of the pipe may also have been caused by unequal expansion and contraction of metal and pot. In the newer apparatus annular introduction of the blast into the metal stream was provided by a special nozzle ; a method which produced a more complete degree of pulverisation than that obtained in the apparatus shown in fig. 3. Details of the annular blast nozzle may be seen in fig. 5.

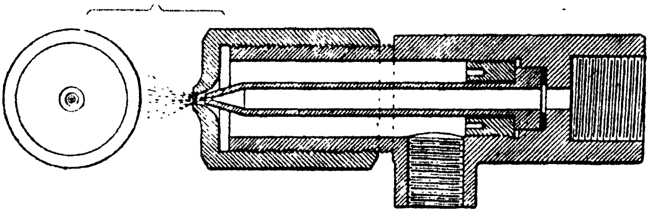

Fig. 5. Details of Nozzle shown in fig. 4.

In operation this nozzle was heated by a gas ring to prevent loss of fluidity or premature solidification of the metal.

More recently still, in America, an apparatus was designed, as shown in fig. 6, in which the molten metal was placed under gas pressure in a closed container. The same gas was used to pulverise the metal, the flow of which could be regulated as desired. The inventor used pressures of from twenty to thirty atmospheres and directed the metal spray directly into a fluid

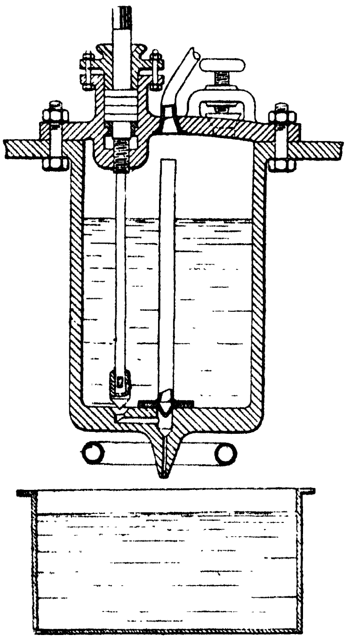

Fig. 6.—Apparatus in which Molten Metal is Fed to the Spraying Nozzle by Gas Pressure.

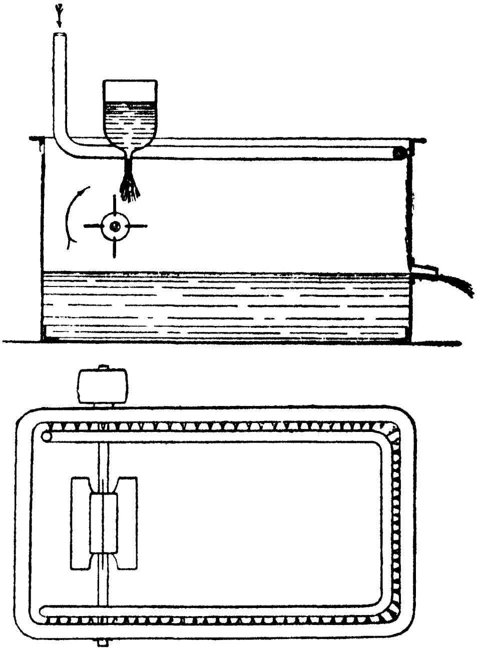

Fig. 7.—Early Mechanical Device for Pulverising Molten Metal.

in order to prevent the oxidation or fritting together of the still hot particles of metal.

Mechanical methods of pulverising molten metal may also be traced back a considerable distance. Fig. 7 illustrates a method, patented in Switzerland in 1893, in which a stream of molten metal impinges upon a rapidly rotating paddle-wheel and is thus projected on to the wall of the container. A film of water is maintained upon the inner wall to prevent the adhesion of the metal spray. The grade of powder could be controlled to some extent by regulation of the speed of rotation of the paddle-wheel.

Fig. 8 shows an apparatus somewhat similar in character, dating from 1899, in which the rotation of the central disc projects the molten metal by centrifugal force. The drops of metal are quickly solidified on contact with the water their size and form being controlled by the location of the runners above the disc.

These and probably many other forms of apparatus were used in the manufacture of metallic powders, *and yet no one had conceived the idea of preparing metallic coatings by holding articles in the metal spray.* Strangely enough, it was an observation of another character which led to the invention of the now well-known metal spraying process. M. U. Schoop certainly deserves credit for observing that, when firing with a small-bore rifle at targets placed in front of a stone wall, leaden bullets adhered to the wall as flattened masses, and when touching or overlapping one another they appeared to be welded together. So impressed was he with the possibilities thus suggested that he commenced a series of experiments. Firstly, a small cannon was charged with lead shot and fired against a flat object. He found, however, that the scattering effect was too great at longer ranges and the shots rebounded at the shorter ranges. No coherent coatings were produced in this manner, but one had learnt that the projection velocity must not exceed a certain limit. This fact was also observed when shot, preheated almost to its melting-point, was similarly fired against the surface to be coated. Field guns use pressures of 3000 or 4000 atmospheres, and the small cannon used will have had projection pressures of several hundred atmospheres, whereas the metal-spray process of to-day operates with at the most three or four atmospheres pressure. Little wonder, then, that the cannon experiments failed to solve the problem. In any case such a method

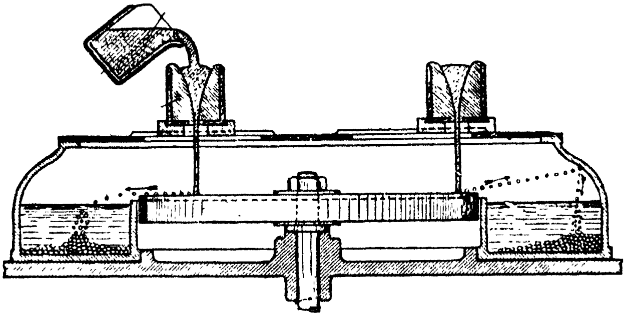

FIG. 8.—Centrifugal Apparatus for Pulverising Molten Lead.

would mean violent and intermittent treatment of the object to be coated. To avoid these defects experiments were next made with the pulverisation and projection of a stream of molten metal with apparatus similar to that in fig. 1. The results were naturally marred by the fact that the blast acted only from one side, and further experiment was therefore made with an apparatus with an annular blast nozzle.

The compressed gas acts upon the surface of the molten metal as well as upon the sides of the descending stream. So successful was this experiment in producing relatively solid and adherent coatings of metal that it was at once decided to develop it so as to make it suitable for commercial practice. The result is shown in fig. 9, a diagrammatic representation of the first large metal-spraying plant to be used in commercial practice. Metal loss, which was unavoidable with this type of apparatus, led to the use of bag filters for the extraction of the metal dust from the escaping blast. Experience with this plant led to the construction in 1909 of the large stationary plant, shown in fig. 10, in which provision was made for maintaining a constant supply of molten metal and for the recovery of the metal powder carried over by the blast. The second plant worked the better because it was fitted with an annular blast nozzle, and thus effected better pulverisation of the metal stream. Both plants suffered, however, from the rapid destruction of the regulating valves for controlling the flow of metal. This trouble would have become an insurmountable obstacle in the case of the higher melting-point metals had not an ingenious device been introduced, which replaced mechanical regulation of the flow of metal by a regulation dependent solely upon the production as desired of a pressure or vacuum

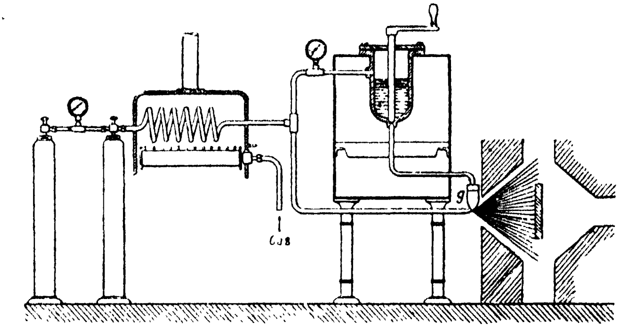

FIG. 9.—The First Molten Metal-spraying Plant suitable for Commercial Practice.

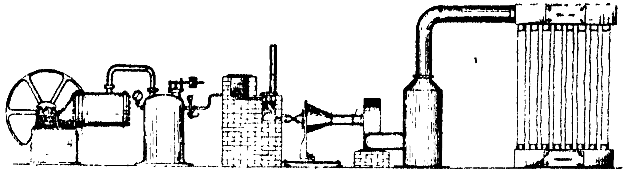

FIG. 10.—Stationary Molten Metal-spraying Plant erected about 1910 in the Zürich Metallisation Works.

in the metal container. The action is instantaneous and easily controlled, and was found to work well in an apparatus as shown in fig. 11, in which the metal was melted in an electrically heated container.

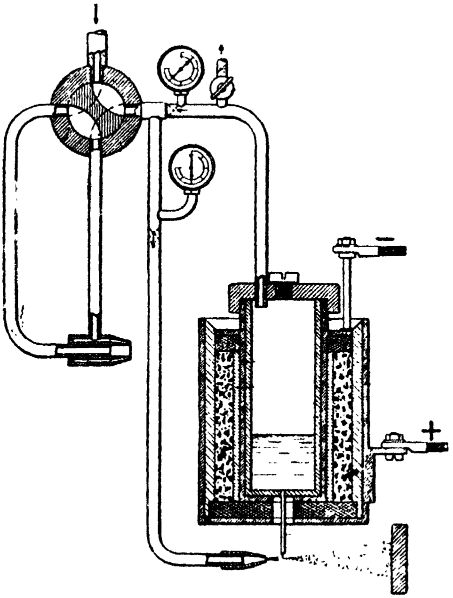

FIG. 11.—Valveless Regulation of Metal Flow in Apparatus for Spraying Molten Metal.

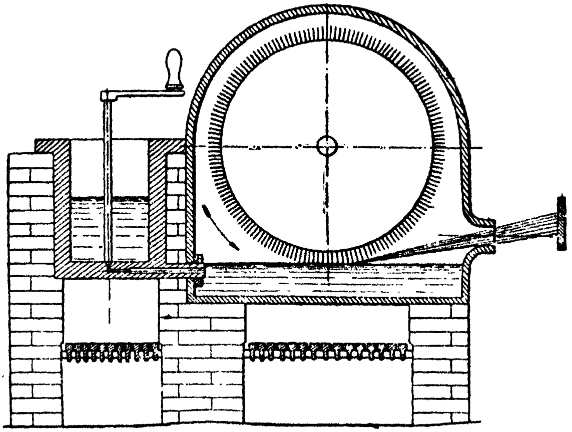

FIG. 12.—Improved Device for Mechanically Spraying Molten Metal.

For a long time the apparatus just described represented the chief or only practical method of metal spraying, but other types of apparatus were tried and are worth mentioning at this point. Fig. 12 shows an early device having provision for replenishing the metal bath during the operation ; it had possibilities as a stationary sprayer.

A somewhat similar apparatus was protected by the same French patent, and is illustrated in fig. 13.

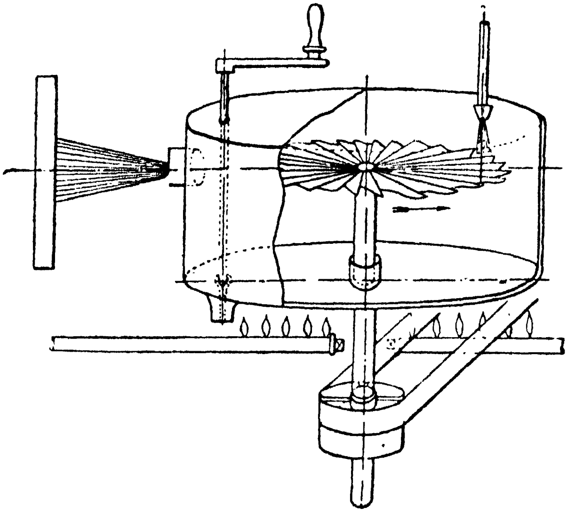

FIG. 13.—Apparatus tor Spraying Molten Metal by means of a Rotating Impeller.

Interesting as may be these and other suggestions, patents, and experiments, they have so far led to no process of practical importance. No large apparatus has been constructed upon these lines ; not that they lacked possibilities, but success in other directions removed the incentive to develop them.

Although spraying apparatus had thus been invented it was stationary and required one to move the article to be coated in front of the fixed sprayer. Without portability and the capability of being directed where desired metal spraying could only have been of small importance.

CHAPTER II.

THE DEVELOPMENT OF THE MODERN METAL SPRAYING PISTOLS.

Powder Process.—Herkenrath deserves the chief credit in the construction of a portable metal-spraying mechanism. Experiments proved that the projection of cold metallic powders failed to produce adherent coatings, but that heated powders so projected did adhere. (This explains why a cone-shaped powder sprayer patented in America in 1900 failed to achieve success.) Two types of *metal-powder* sprayers have been used, namely, the "sandblast" and "cyclone." Heating of the powder is caused either by blowing it actually through a flame or by projecting it by means of a heated blast. Fig. 14 shows a practical metal-powder spraying apparatus

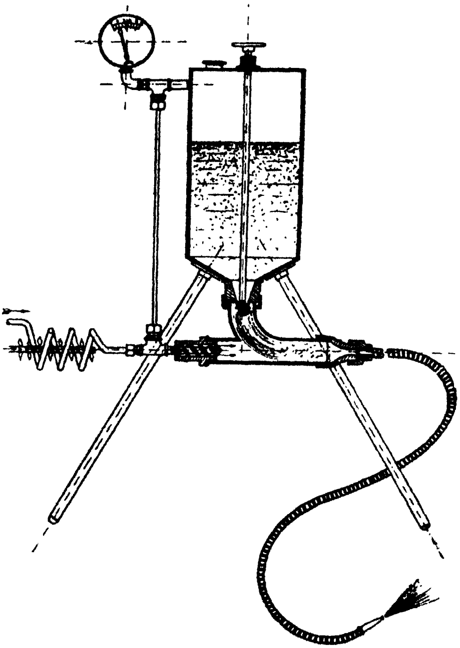

FIG. 14.—Practical Metal-powder Spraying Apparatus designed according to the Principle of a Sand Blast Machine.

built on the "sand blast" principle. With this device the regular and uninterrupted introduction of the metallic powder into the transporting blast is of the greatest importance for economic and continuous operation. Fig. 15 shows details of the lower part of the container shown in fig. 14.

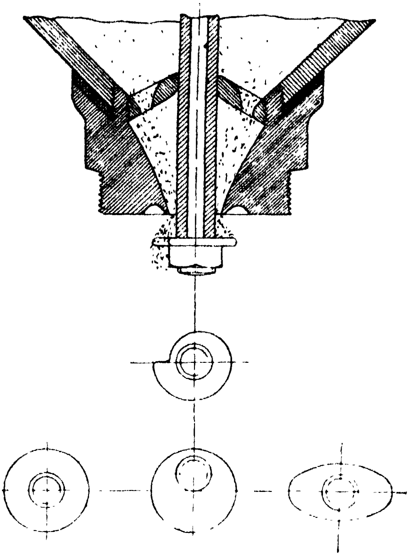

FIG. 15.—Details of the Lower Part of the Container shown in fig. 14.

The eccentric, oval, or cam-shaped valve heads should be noted. They prevent sudden falls of large quantities of the powder such as occurred when circular valve heads were used. It was found that heating the blast alone did not permit of the production of solid adherent coatings, and that it was necessary to heat the powder on expulsion nearly up to its melting-point. This was accomplished by using a nozzle as shown in fig. 16, in which the metal powder projected by the blast passes through the central opening, while an annular blowpipe flame is produced by the blast and gas

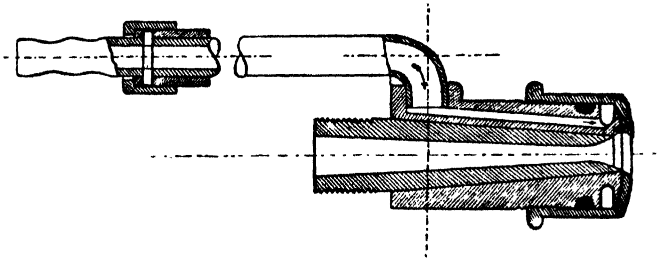

FIG. 16.—Nozzle with Annular Gas Burner for Heating the Metal Powder immediately before it is Sprayed.

(under pressure), which is admitted to the outer annular passage through the elbow at the side and burns at the nozzle. The gas employed may be chosen so that the temperature of the flame and its chemical characteristics are suitable for use with any desired metal.

Experience with this type of nozzle proved it to be so effective that preheating of the airblast was superfluous. It thus became possible to simplify the whole apparatus which was used in practice in the form shown in fig. 17. This is a workmanlike, portable device, in which the metal powder falls from the bottom of the container into the transporting blast and is heated on emission from the nozzle by an annular gas flame. Such sand-blast type sprayers are suitable for comparatively coarse powders; the minute particles of the finer grades of powders tend to stick together and clog up the valve aperture. Such very fine powders are, therefore, sprayed by means of the "cyclone" apparatus, of which fig. 18 may be regarded as a typical cross-section. This operates, so far as the movable nozzle is concerned, in exactly the same manner as does the apparatus just described, but instead of the powder falling from the container into the blast, the latter is introduced into the container below the powder and escapes through a flexible pipe attached to the top of the vessel. In this way a portion of the powder is constantly whirled up and carried over by the blast without the same danger of clogging up the blast-passages. Two small hand-operated valves control the apparatus in use.

FIG. 17.—Improved Type of Metal-powder Spraying Apparatus at work. It is operated on the sand blast principle, and has a gas heater at the nozzle.

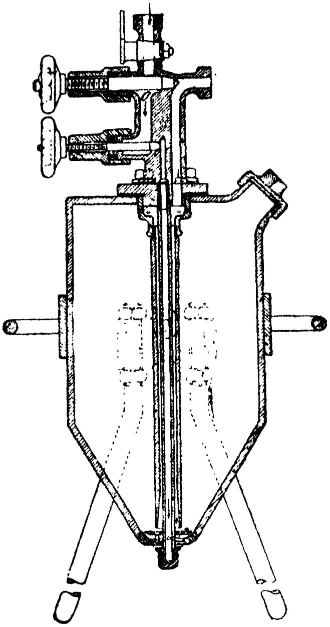

FIG. 18.—Cross-section through the " Cyclone " Metal-powder Sprayer as used for very Fine Powders.

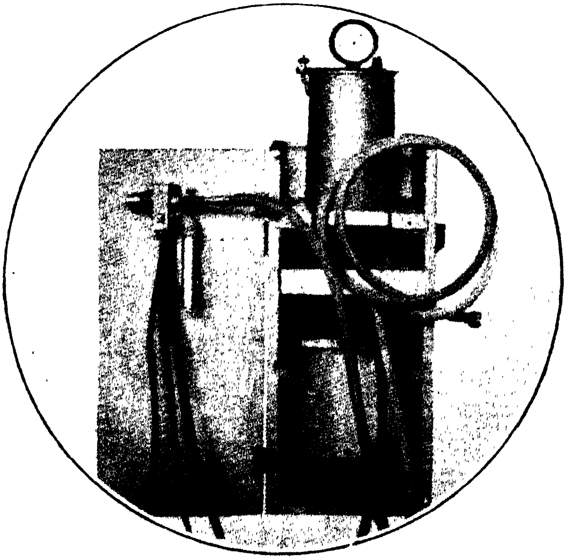

FIG. 19.—American " Gravitas " Metal-powder Sprayer.

About 1924 the " Gravitas " powder spraying equipment became popular for spraying zinc, tin and lead. This apparatus used either acetylene or hydrogen and oxygen in combination with compressed air, and is shown in fig. 19.

The " Gravitas " consists of a cylindrical container which holds about twenty pounds of powdered metal. At the top is fitted a removable cover to which is attached a pressure gauge, and at the bottom of the container is placed an ingeniously constructed gas dust-distributor. From the distributor the metal dust passes through a rubber tube to the spraying tool or " gun," which, by an ingenious construction, passes it between two concentric flame zones at the muzzle, where it is instantly heated to a plastic state and impacted on the surface to be coated.

More recently Dr. Schoop has strongly advocated a similar simple type of blowpipe burner powder sprayer in articles in the technical press.

A powder pistol designed by Schoop is illustrated in fig. 20. There is a separate container for the powder which is agitated by the compressed air entering at the bottom ; the top outlet of the container is also connected to a compressed air supply which carries the powder to the central orifice of the pistol. Oxygen and combustible gas are mixed and form a flame around the central orifice. The compressed air for projecting the heated powder is directed by two adjustable nozzles arranged on either side of the main nozzle.

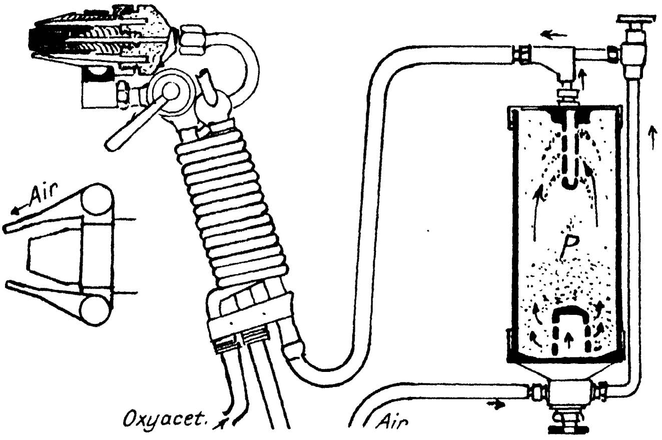

FIG. 20.—Early Schoop Powder Pistol.

One of the early Schori powder pistols, the forerunner of the modern type, is shown in fig. 21.* The underlying principle is the transference of the powder from the container to the nozzle by suction created by compressed air. Compressed air passes through a channel *a*, enters the annular space *b* in a tangential direction and leaves by a restricted opening. This creates a partial vacuum in the hole *c*, and at the bottom of the hollow handle.

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* *Brit. Pat.*, 221828.

The powder contained in this handle is thus sucked up the pipe *d* and the channel *c* and ejected from the nozzle. The quantity of powder can be regulated by screw *e*. To provide good suction action, openings to the atmosphere are made in screw *e*, regulated by *j*, and also at the bottom of the handle. The handle is dovetailed into the pistol body. The combustible gas enters the nozzle through a hole at right-angles to channel *f*. The amounts of compressed air and gas are regulated by valves *g* and *h* in channels *a* and *f*, the form of which is shown in section *Z*. By pressing the member *i* the valves are opened. The atmospheric air serves for the combustion of the gas.

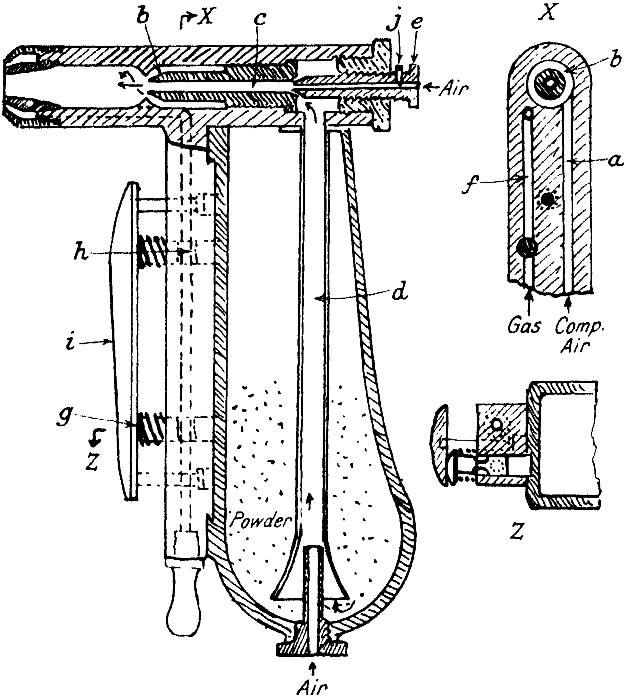

Fig. 21.—Early Schori Powder Pistol.

One disadvantage of the pistol is the necessity for frequent charging of the container with powder.

Development of the Wire Spraying Pistols.—We have seen that *molten-metal* sprayers were practicable but stationary. The *powder* sprayers were admittedly portable, being operated almost as easily as a paint brush, but they did not produce good results with metals of high melting-points. This was because the higher the melting-point of the metal to be sprayed, the greater was the proportion of the powder which failed to be heated up to the particular temperature requisite for the production of solid adherent coatings. Colder particles simply rebounded from the surface, their projection having been a waste of energy. The problem was, therefore, how to produce such regular operation that only just so much metal as could be satisfactorily heated and sprayed was admitted to the nozzle. Experience with the powder process pointed to the advisability of returning to the use of molten metal; and yet portability was essential. The solution arrived at was to melt only so much metal as could be projected immediately. It was again Herkenrath who conceived the possible mode of operation. Experiments were undertaken, and it was found that continuous melting and pulverisation were possible if a wire of the metal was fed forward as shown in figs. 22A, B, and C. The figures illustrate diagrammatically three of the experiments. In the first case the wire was fed into and melted by a blowpipe flame, while in the second case, suitable for metals of higher melting-points, wire was similarly fed to, and melted by, an electric arc of which it formed one pole. Electricity was also used in the third experiment, but the

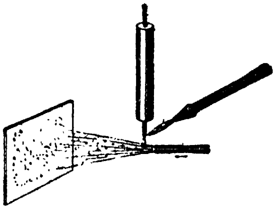

FIG. 22A.—Diagrammatic Representation of Experiment to Determine whether Wire could be Melted and Sprayed.

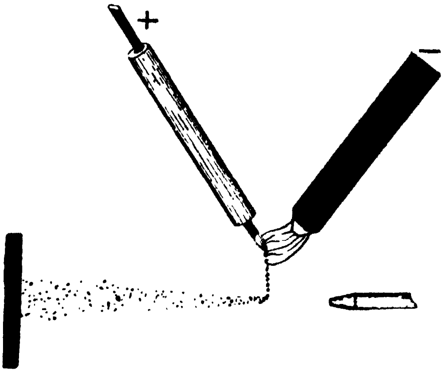

FIG. 22B.—Diagrammatic Representation of Experiment to Determine whether Wire could be Melted Electrically and Sprayed.

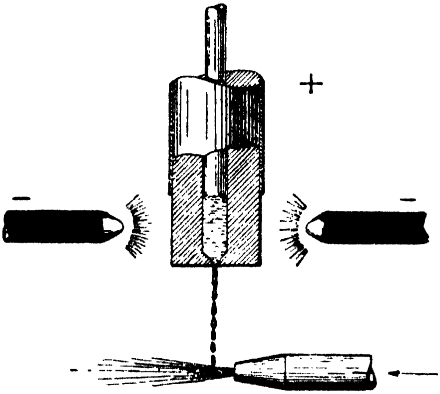

FIG. 22C.—Improved Experimental Design for Electrical Wire Melting and Spraying.

wire did not form one pole of the arc. In all three cases a gas blast from the side scattered the metal as particles. It was thus shown to be possible to prepare a coating by blowing compressed air into a falling stream of metal melted in such a manner. The apparatus shown in fig. 23 was constructed, and in principle this is still to be found in hundreds of metal-spraying pistols now in use. A central tube leads a metal wire into an annular flame and thence into an annular transporting, pulverising, and projecting, or spraying, blast. The gas for the flame and the blast emerge from annular passages concentric with the wire itself. So successful was this device that for the time being the experiments with electrical heating were dropped. It was, however, no easy matter to design an apparatus in which the gradual, steady advance of the wire was so timed as to be in exact harmony with the melting of its end and the spraying of the molten metal so produced. For continuous working and uniform action such co-ordination of the three functions was essential. It was found possible to unite two of the three factors by using the spraying blast to operate the wire feed mechanism. By means of a small air turbine the blast was made to operate rollers which

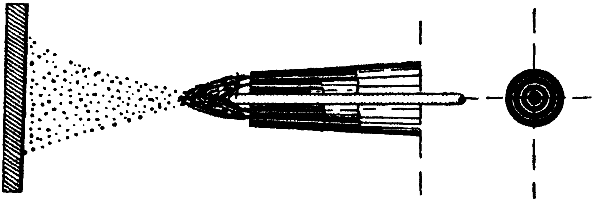

FIG. 23.—Improved Experimental Design for Wire Spraying.

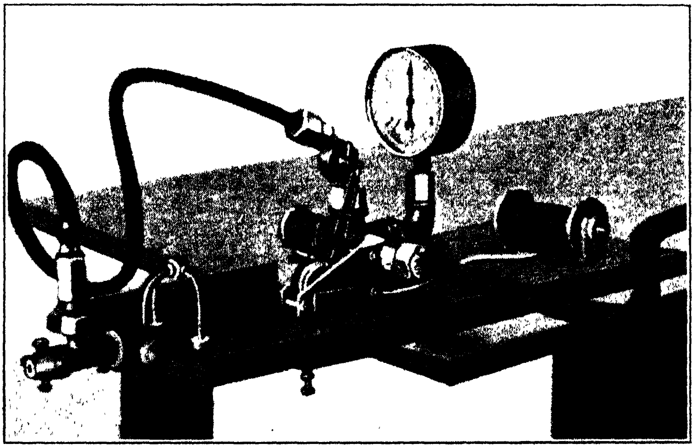

FIG. 24.—Design of the First Experimental Wire-spraying Apparatus with Co-ordinated Feed, Melting Flame, and Blast.

gripped the wire. When the rollers were revolved the wire was advanced into the nozzle and unrolled from the supply spool (see fig. 24), while the blast exhausting from the little air turbine passed through a pipe to the outer annular passage of the spraying nozzle. Thus, given a supply of wire, gas, and compressed air, spraying could be controlled by two regulators, the one governing the intensity of the melting flame and the other governing simultaneously the wire feed and spraying blast. In operation the wire was melted continuously, for as it advanced and protruded from the nozzle it was pulverised and driven forward by the exterior concentric cloak of the now expanding air blast. Regulation was accomplished empirically, but once the mechanism had been satisfactorily adjusted it could be stopped and restarted instantly. No considerable loss of metal was thus necessary, and in practice the wire-spraying apparatus worked as economically as could be desired. Though comparatively compact, this experimental apparatus was far from being as mobile as a paint brush. It was, we believe, Herkenrath who, therefore, designed an apparatus similar in principle to that just described, but made so compact in form that it could be held in one hand like a pistol. This first metal-spraying " pistol " is shown diagrammatically in fig. 25.

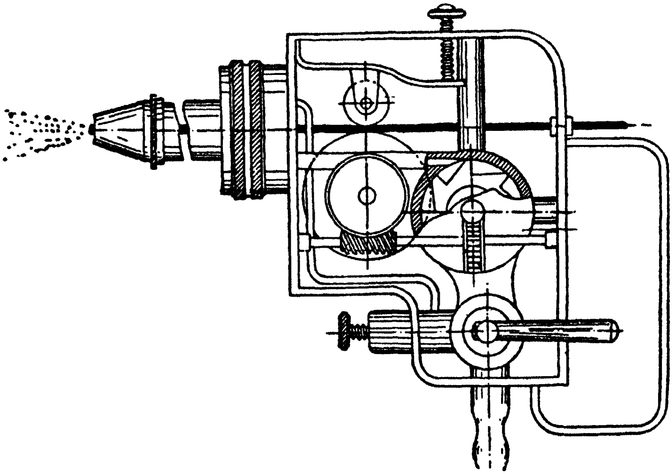

FIG. 25.—Sectional View of the First Metal-spraying Pistol.

The nozzle used with the first pistol is shown in longitudinal section in fig. 26. The front view may be seen at the right.

Undoubtedly it was the introduction of the wire-spraying pistol which brought the metal-spraying process into practical operation on such a large scale. This apparatus, differing little in weight or size from an army revolver, approaches the ideal apparatus, *i.e.* one with which one can metallise in the same way as a painter uses a paint brush. Metals so difficult to fuse as platinum were sprayed by the pistol, the gas consumption of which varied according to the melting-point, specific heat, etc., of the metal sprayed. The detail mechanism of the pistol has undergone numerous modifications, some of which are shown in figs. 27-31.

The first of these, fig. 27, shows a side view of the pistol used at one time in Berlin by the German "Metallisator" Company. It differs from that already described, chiefly in that the worm-gear shafts of the wire feed

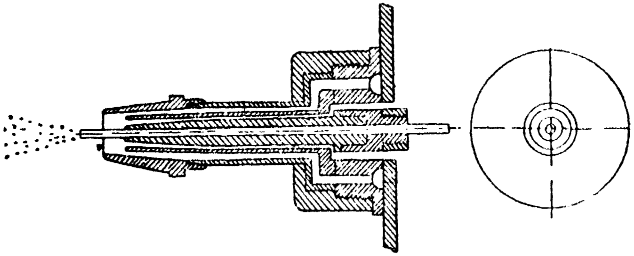

FIG. 26.—*Left*: Longitudinal Section through the Nozzle of the Spraying Pistol illustrated in fig. 25. *Right*: Front View.

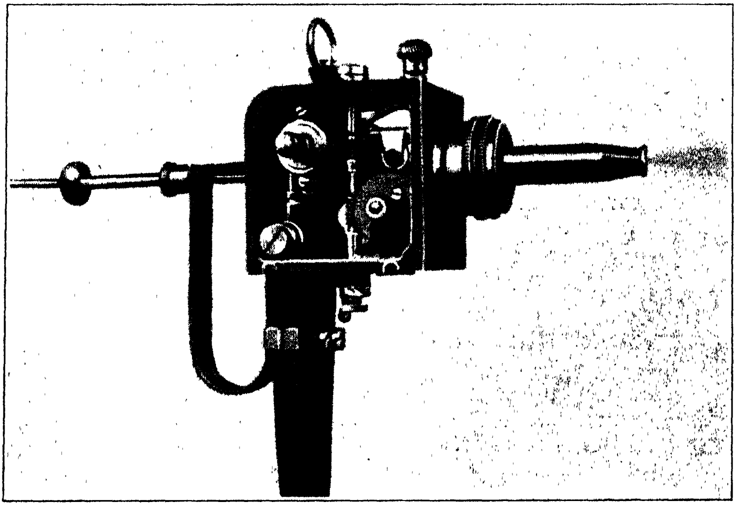

FIG. 27.—Model of the Wire-spraying Pistol formerly used by the German "Metallisator" Company.

mechanism were arranged more compactly, as may be seen in fig. 27. The newer type was a step towards greater compactness. Subsequent designs have all had the same tendency up to a point, but beyond that little advance in this direction has been possible, because absolute reliability and accessibility are as important as handiness and lightness. A compromise as regards possible forms of especially accessible, light, or compact pistols has been achieved in almost all countries, and it speaks well for Herkenrath's first design that the present-day pistols differ therefrom in detail only. Fig. 28 illustrates the type of pistol used some years ago by the French company.

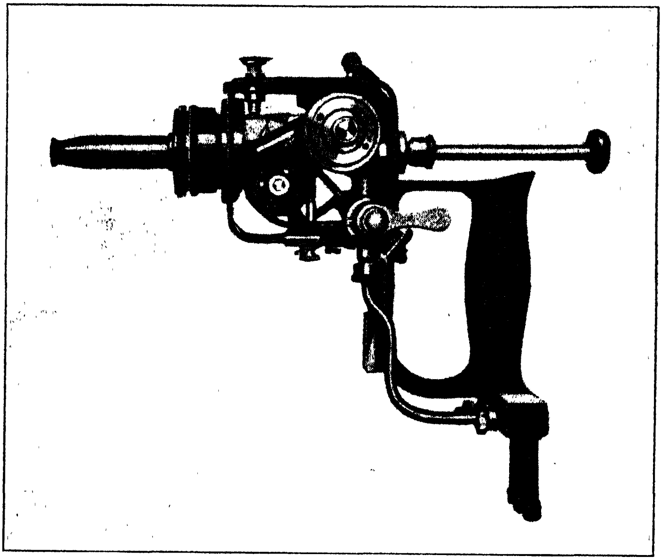

FIG. 28.—Wire-spraying Pistol formerly used by the French Company.

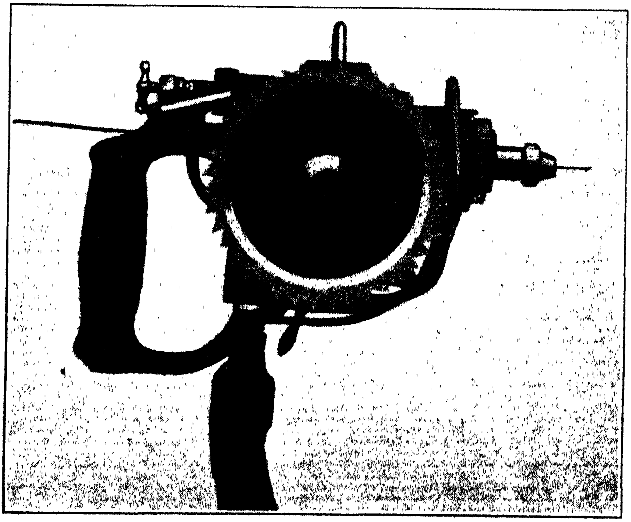

FIG. 29.—Wire-spraying Pistol Modified by the French Company to obtain a Slower Turbine Speed, but found unsatisfactory in practice.

The French company designed and produced a pistol which was to be especially suitable for light or thin wires, such, for example, as aluminium and the noble metals, the supply reel of which was attached to the pistol itself instead of resting on a separate stand as in the usual practice.

For some purposes this arrangement, giving increased mobility and handiness, was a distinct advantage.

A peculiarity of one such wire-spraying pistol (see fig. 29) was the elimination of all reduction gearing; the air turbine was greatly increased in size and was directly coupled to the wire feed rollers. The promised advantages of this simplification and use of a slower running turbine were unfortunately more than counterbalanced by the disadvantages inherent in the design. Increased inertia effects of the bigger rotor made instantaneous stopping and starting impossible, and, so far as the authors are aware, all designers of wire sprayers have returned to the use of the smaller air turbine.

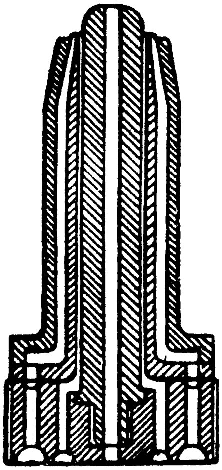

Fig. 30A.—Section through Nozzle designed for Spraying Thick Wires.

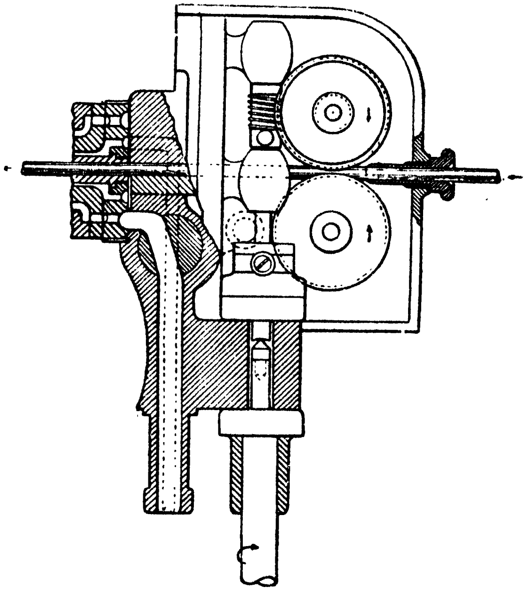

Fig. 30B.—Gas Connections and Feed Mechanism of the Thick Wire-spraying Device.

The second type of pistol here mentioned was designed for spraying very heavy or thick wires, in which operation it appeared to be advisable to separate the supply reel and wire feed mechanism from the actual melting and spraying portion of the apparatus in order that its handling in operation should not be too cumbersome. Fig. 30A shows the nozzle (somewhat enlarged), and fig. 30B the gas connections and wire feed rollers of this heavy wire-spraying pistol, which contained no air turbine.

Instead of the usual arrangement, the air turbine, the motive-force for the wire feed rollers, was placed on a special separate stand on the floor together with the supply reel, and the feed rollers were driven by means of a flexible shaft connection. Diagrammatically this is shown in fig. 31.

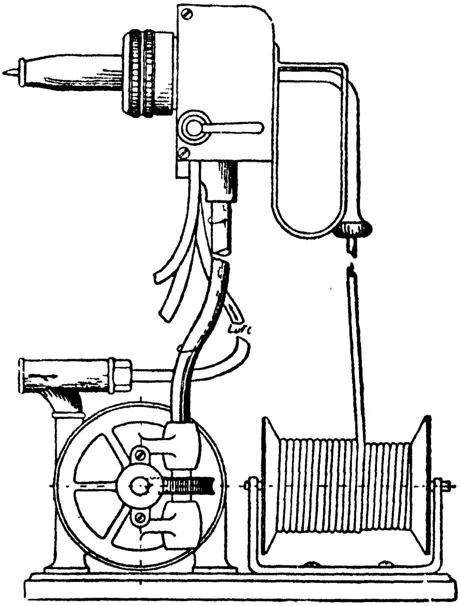

FIG. 31.—Complete Assembly of the Thick Wire-spraying Device employing Separate Wire Feed Turbine.

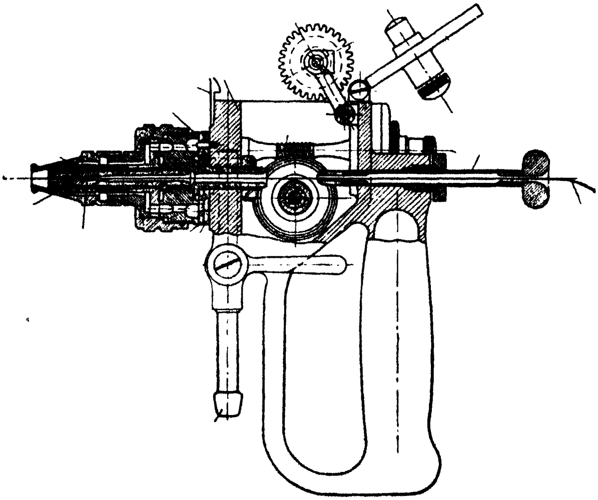

FIG. 32.—Side Elevation of Pistol D.

The survey of the wire spraying process given above briefly outlines the development of the wire-spray pistol up to the outbreak of the Great War in 1914. Since that time the holders of the Schoop patents in the various

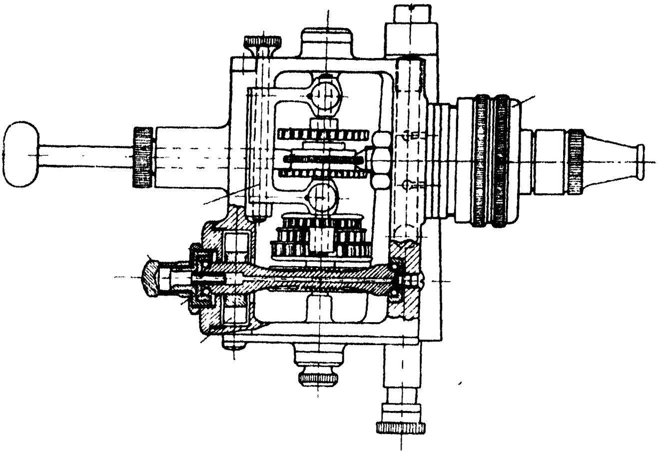

FIG. 33.—Plan of Pistol D.

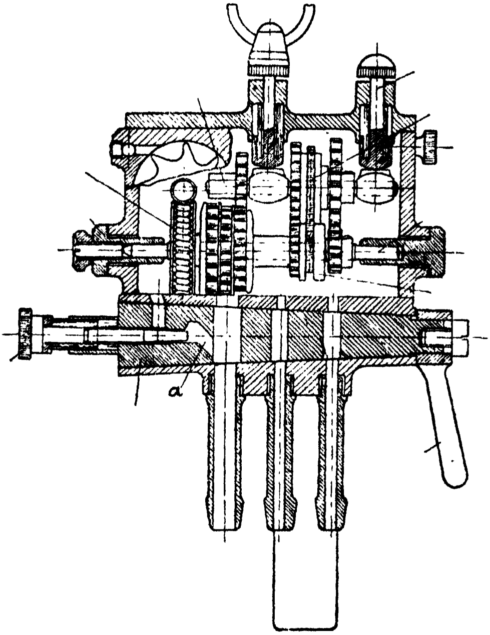

FIG. 34.—End Elevation of Pistol D.

countries have developed the apparatus along certain lines, three of which will now be mentioned. In Zürich, also, all special models and variations of the wire-spray pistol were discarded, and up till about 1925 only two types were employed there : pistol D for thin wires of metal relatively difficult to melt, such as zinc, aluminium, copper, brass, iron, nickel, etc. ; and pistol E for thicker wires of metals easy to melt, chiefly for tin and lead. The illustrations 32, 33, 34, 35, 36, 37 and 38 show the details of pistol D, while pistol E is, in the main, quite similarly constructed. The most important difference lies in a larger turbine, because for the advance of thicker wires more power

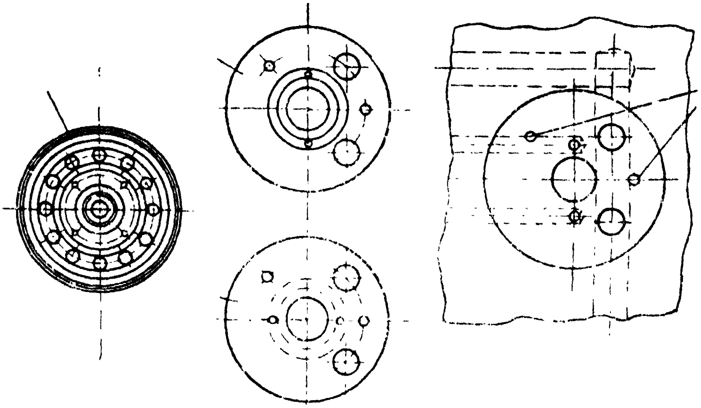

FIG. 35.—Gas or Baffle Plates.

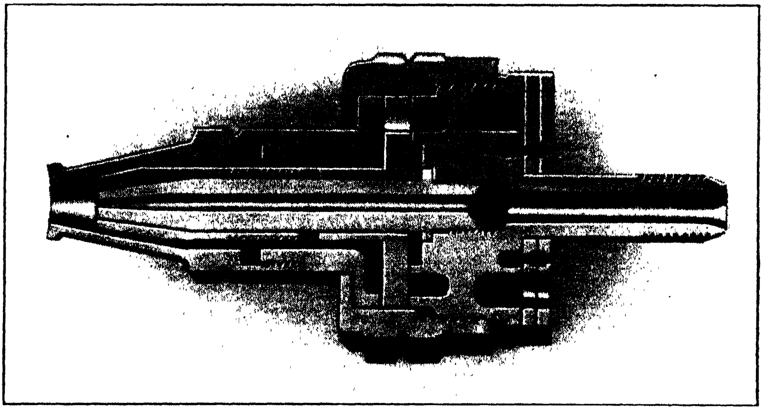

FIG. 36.—Section through the Nozzle System of the D Pistol.

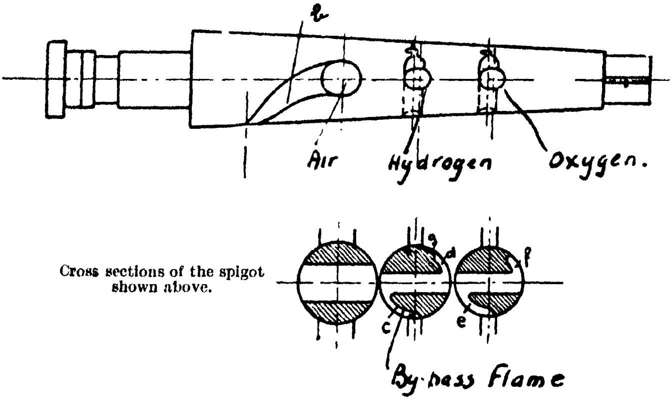

FIG. 37.—Spigot of Stop-cock showing By-passes and Apertures.

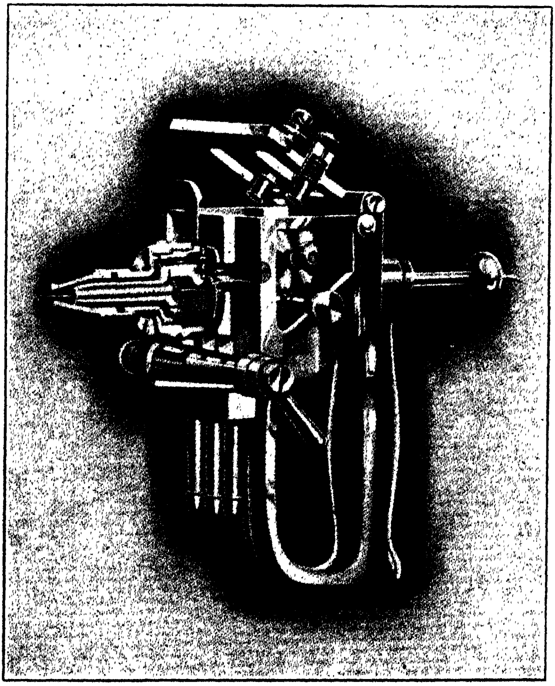

FIG. 38.—Pistol D.

is required. The handling of both models is the same, similarly all detail parts of both types are the same and made according to a standardised pattern so that they can be interchanged at any time. Below we give a detailed description of pistol D.

The nozzle head is fixed to the front wall of the casing of the apparatus by means of a hexagonal nut. Between the casing and the nozzle head are the so-called gas plates (fig. 35), which each possess two small holes, one for the coal-gas or hydrogen, and the other for the oxygen. The size of these holes is such that with a definite pressure, just that quantity of gas arrives at the nozzle which is necessary to melt the wire. The annular channel in the two gas plates serves simultaneously as a mixing chamber for the gas, especially because the two gas holes in the two plates are placed exactly at 90° to one another. The gas tube is a sliding fit over the wire tube as the drawing (fig. 32) shows. It is built in two parts, the back part sits with its flange on the nozzle head while the front part, provided on the outside with grooves for the air, is only screwed so far back until it sits well upon the wire tube. The air channel is similarly in two parts, the front cap is only screwed on after fixing the flange part on to the nozzle head, by means of a union nut, until it comes up against the gas tube (see fig. 36). In this manner the three tubes are always accurately centred and the cross-section for the gas and air is always maintained at the normal size, as is absolutely necessary. For various sizes of wire, tubes with various diameters are used. The feed mechanism is composed of a small air turbine, a worm drive, a tooth gearing, a wire feed roller, and a pressure roller which presses the wire against the feed roller by means of two spring buffers. The turbine consists of a bladed wheel which rests on a shaft running in ball-bearings. The shaft is drilled through so as to admit oil to the two ball-bearings and the worm drive from a small stuffing-box. The worm gear of the turbine shaft engages with a toothed wheel fixed to the intermediate shaft, this shaft runs in two removable bearings of which one is provided with a steel screw to take up axial pressure. A small-toothed wheel fixed to this intermediate shaft transfers the movement by means of gearing to the wire feed rollers. The latter grip the pressure roller which runs loosely on the gearing shaft. Both rollers are connected together through two gear wheels so that the pressure roller also takes part in feeding the wire. The toothed gearing possesses three steps in pistol D, and two in pistol E. By simply removing the particular reduction gear wheels on the gear shaft, two or three different speeds can be given to the feed rollers with the same constant turbine speed. The case or body is an aluminium casting, the form of which may be plainly seen from fig. 38.

The stopcock has a hole each for coal-gas or hydrogen, oxygen, and compressed air. From the passage for compressed air, *a* (fig. 34), the size of which can be regulated by a screw, two smaller channels branch off to the turbine. Besides the channel *b* (fig. 37), which proceeds from the air hole, channels *c*, *d*, *e*, and *f* lead from the gas holes along the outside of the cock, and *d* is continued by a fine notch *g*.

Admission of the gases and compressed air takes place through three separate and armoured flexible tubes which are joined to the apparatus by rubber connections.

With the cock completely opened the air does not pass through the channel *b* to the turbine, but through channel *a*, so that it must pass the regulator which is so fixed that the turbine attains its normal speed of revolutions, *i.e.* 35,000 r.p.m. in pattern D, and 32,500 with pattern E.

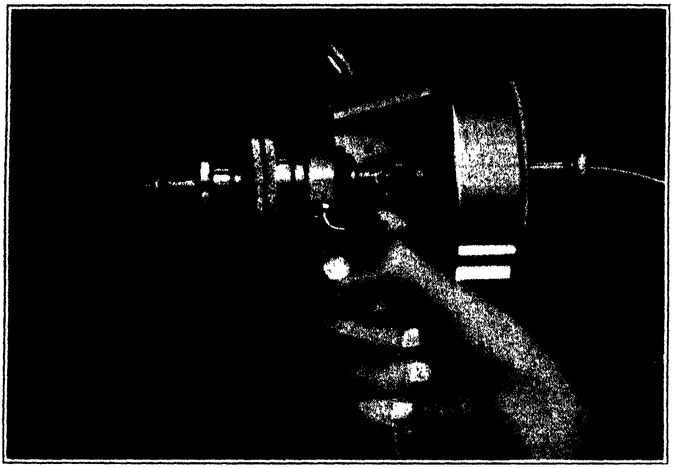

FIG. 39.—Simplified Wire-spraying Pistol.

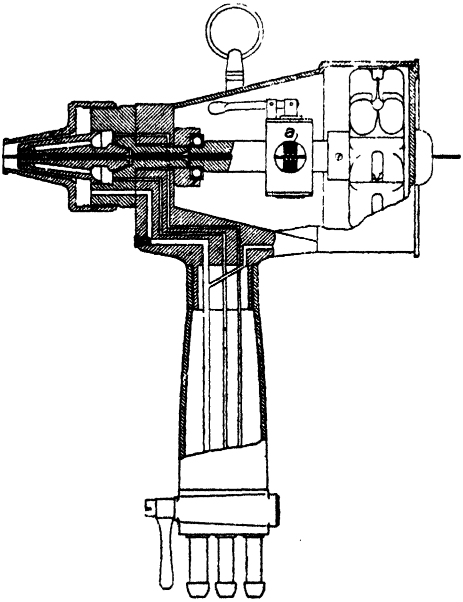

FIG. 40.—Diagrammatic View of the Screw-feed Pistol shown in fig. 39.

When work is finished, the pistol is put out of operation by simply turning the cock into its original position, only the small by-pass flame remaining, so that restarting at any time is possible with the one movement of the hand.

Dr. Schoop's elder son, Werner, attempted to simplify the construction of the wire pistol, and reported that under the guidance of Matzinger, a skilled mechanic produced the form of pistol illustrated in figs. 39 and 40, in which a small Pelton wheel, rotating at 4000-5000 r.p.m., drives a screw-cutting type of wire feed, thus replacing the usual very high speed air turbine and triple reduction gearing. The pistol illustrated is obviously smaller, lighter, and cheaper to manufacture than the standard types referred to above. The new feed consists mainly in pushing the wire to be moved into the interior of the hollow axle of the turbine, causing the wire to engage with several dies, which are provided with thread-like pressure faces and rotate with the axle of the turbine. When the turbine comes into operation the dies impress upon the outside surface of the wire a kind of screw or spiral indentation, which causes the wire to be fed forward. In practice the pressure

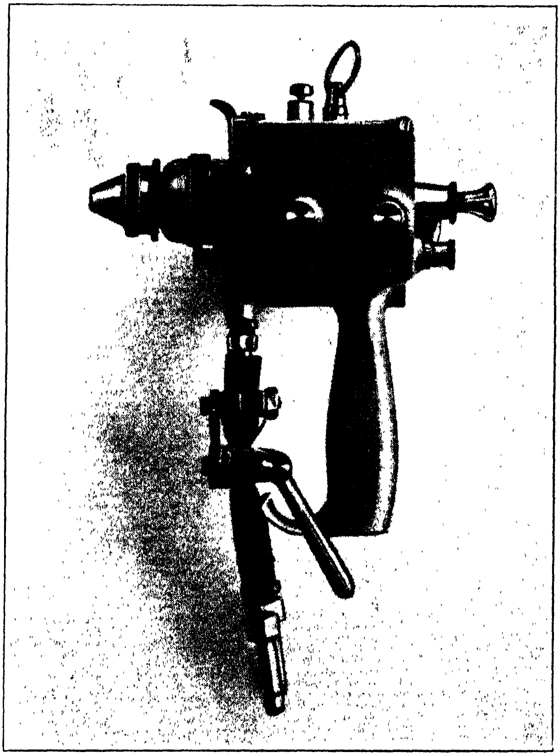

Fig. 41.—Metal-spraying Pistol as used in England and France (Hand-grip indicates size).

dies are supplied with small cutting wheels, which rotate about the wire, making a certain definite angle with it. Every revolution of the turbine thus produces a forward propulsion of the wire along the pitch of the spiral, so that the ratio of reduction is very large. It can also be varied within certain limits, simply by varying the inclination of the pressure wheels to the axis of the wire.

A type of pistol employed in England and in France, and which has been produced in large numbers, is illustrated in fig. 41.

The " Schoop " type of valve has here been replaced by the " Burali " type, which may be seen in the illustration located just in front of the hand-grip and acting upon the rubber tubes. Although extremely simple in operation this valve mechanism sometimes gives trouble when the rubber has perished to any considerable extent.

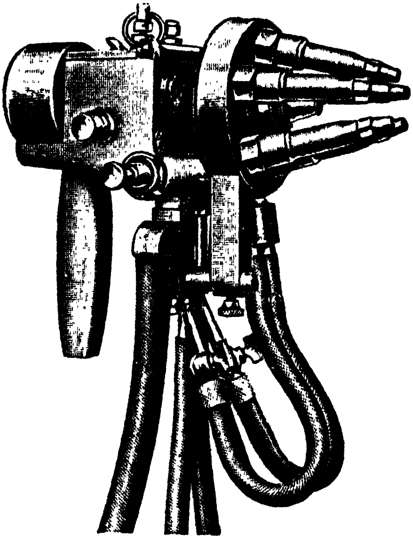

Fig. 42.—Preheating Jets surrounding Wire-spraying Pistol.

The design of the wire-spraying pistol used in America was somewhat different from the types already illustrated. It was similar to a German-made pistol which was also fairly widely used in England.

Preheating.—In about 1924 preheating of the article to be sprayed was strongly advocated. It is now known that, although condensed moisture on the surface should be avoided, certain properties of the sprayed deposit are not improved by such preheating. A typical pistol with preheating jets is shown in fig. 42. Preheating ovens have also been in vogue, some being arranged as rumblers for spraying small articles (fig. 43).

Molten Metal Pistol.—In August, 1921, Mr. C. J. Jung of Amsterdam acquired a licence from Dr. M. U. Schoop to use his wire pistol and a workshop was fitted out at Diemen, a small village near Amsterdam. Owing to the restricted nature of the licence, however, it was found impossible to make an economic success of the venture.

Mr. H. J. Versteeg, a foreman with C. J. Jung & Co., was familiar with the restrictions on Mr. Jung's licence and often suggested that steel windows and door frames ought to be included, but this was found to be impossible since an exclusive licence for this class of work had been granted to Messrs. Braat at Delft. One evening, in the Spring of 1924, Mr. Versteeg called on Mr. Jung and showed him a piece of cardboard and a few pieces of sheet iron which had been sprayed with tin by a process not using wire. The apparatus which Versteeg had built was of somewhat imperfect construction, but after many experiments and tests an apparatus was made which would spray tin, lead and very low melting-point alloys; but zinc spraying was

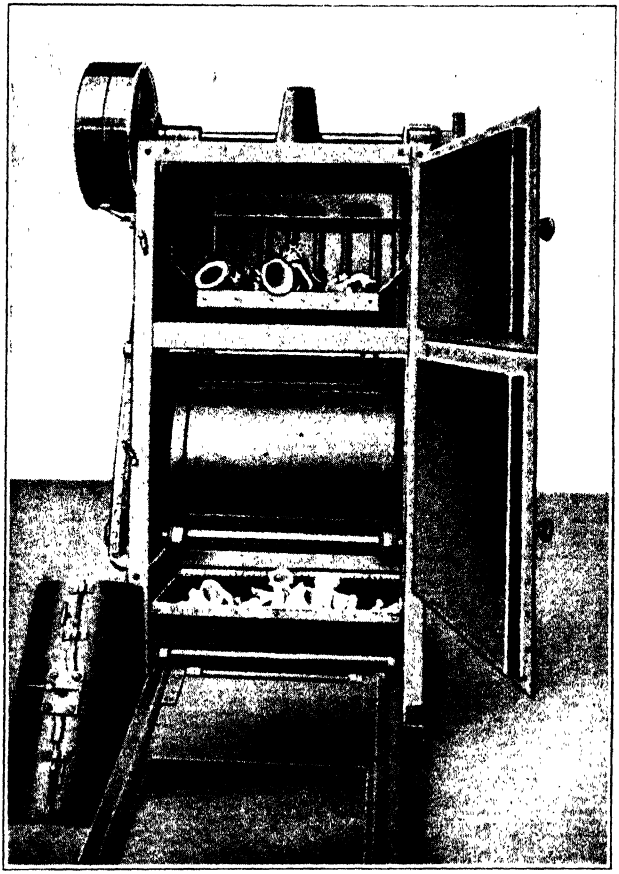

FIG. 43.—Machine for Simultaneously Metal-spraying Numerous Small Articles : Open.

still impossible. Although Jung was aware that this apparatus was still primitive, he decided to cover the principle embodied in it, and a patent was granted by the Netherlands Patent Office on 22nd October, 1924. This was the first application for the "vertical" type of metal spraying apparatus, the construction of which can be seen in fig. 44. The molten metal was held in a reservoir, into which compressed air was blown; the flow of metal from the reservoir was controlled by a needle valve, and the temperature maintained by a blowlamp beneath the jet.

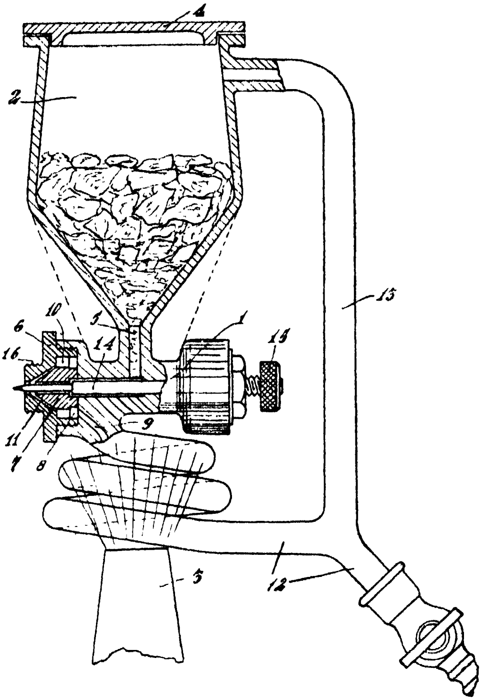

FIG. 44.—Early Vertical Type Molten Metal Sprayer.

The new method was called the "Prakticus" system and orders were soon received, the first of which was tin-spraying the inside of a milk-transporting can at the end of October, 1924.

It rapidly became apparent that the spraying of zinc was essential. The limitation of the apparatus was the low temperature employed, for with the aid of a second blowlamp zinc could be sprayed for a few minutes, after which stoppage occurred owing to the zinc oxide and zinc-iron compounds formed in the container.

A few months later work on the vertical pistol was abandoned and experiments commenced on a horizontal type with the air feeder and nozzle just in front of the container, as shown in fig. 45. Both the metal container and a cowl were covered with asbestos to conserve the heat, and the metal

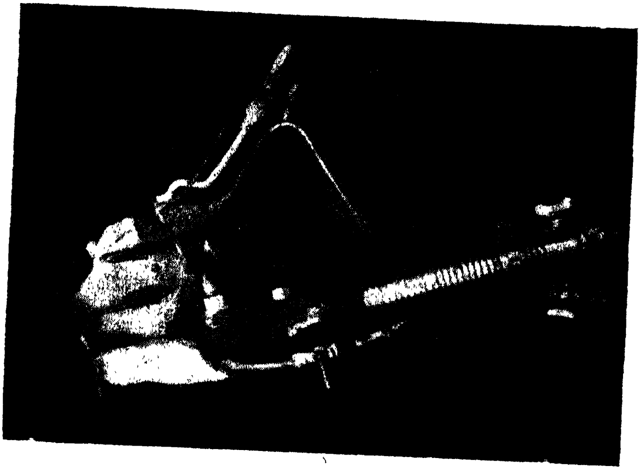

FIG. 45.—Early Horizontal Type Molten Metal Pistol.

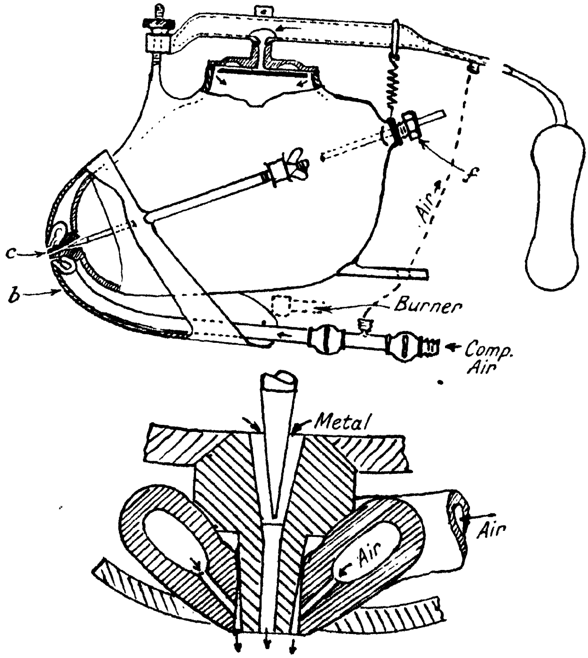

FIG. 46.—Early Mellowes Pistol, Pressure Type.

was kept molten by a petrol blowlamp, as no gas was available in the village of Diemen.

Many alterations were made to the design before Jung finally patented, in September, 1926, a pistol with a Bunsen burner supplied with coal gas from the town mains.

This invention was brought to the notice of Mellowes & Co., Ltd., of Sheffield, whom Jung represented in Holland, and the development in the British Empire and certain other countries was taken over by them, the process being given the trade name " Mellozing."

The construction of the first British* pistol is shown in fig. 46. The container for the molten metal is sealed by a cap through which compressed air from the hollow handle is passed, thus providing a pressure feed for the metal. The nozzle *c*, separate from the container, is held in position by a detachable shield, which guides the flame from a burner along the wall of the reservoir. The size of the orifice is varied by a needle valve which passes through the stuffing box *f*.

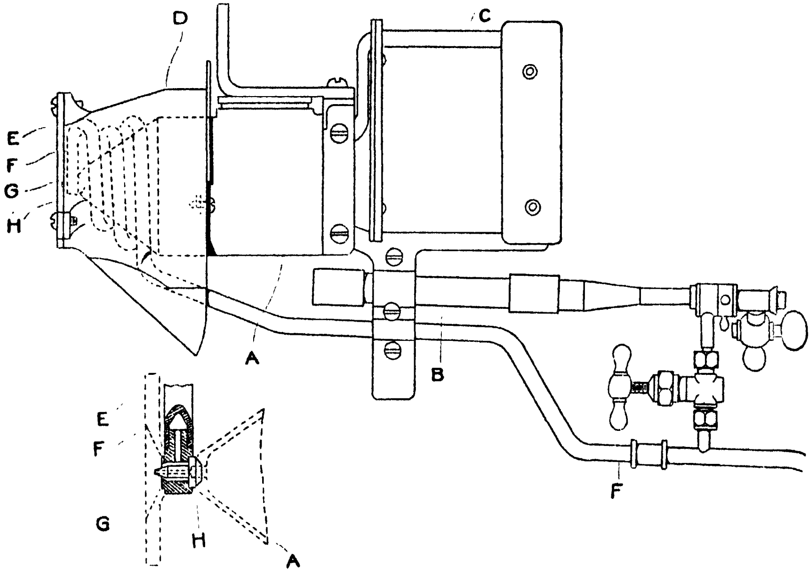

Fig. 47.—Gravity Feed Horizontal Molten Metal Pistol.

This pressure feed pistol was never used very much commercially, but was replaced by a somewhat similar design using a gravity feed, as illustrated in fig. 47, patented in 1930.† At the rear of the conically-nosed container is an asbestos shield and a handle, underneath which is a burner B arranged to direct its flame along the walls of the container and round the air pipe connected to the nozzle H. The air pipe is arranged spirally round the

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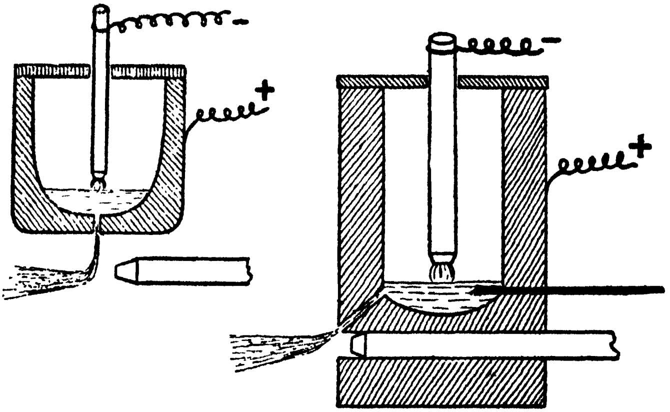
* *Brit. Pat.*, 276955.

† *Brit. Pat.*, 349031.

container, forming a spring which tends to remove the nozzle from its seat. The latter is held in position by a clamp E, the removal of which allows the nozzle to be inspected and replaced by rotating G, the air feeder. An asbestos screen is fixed behind the container to protect the operator's hand. The molten metal is fed by gravity, necessitating a slight downward inclination of the pistol. With this construction the advantages claimed were (*a*) the air was preheated prior to its admission to the nozzle, (*b*) accessibility of the nozzle, (*c*) thermal efficiency.

There are disadvantages in this type of pistol. The choice of spraying metal is limited to those which have low melting points and it is necessary to construct the apparatus of a high melting point metal. The erosion and attack of the metal parts by the zinc is rapid, necessitating frequent maintenance. The typical life of the various parts was as follows :—



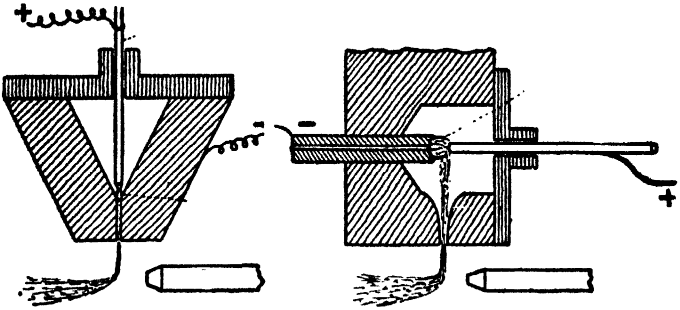
Figs. 48 and 49.—Early Attempts to use Electrical Heating in Metal Spraying.

Nozzle	3 hours	Front clamping plate	2 weeks
Metal container	3 days	Air Heating Tube	3 weeks
Air feeder	1 week	Cowl	4 weeks

Light alloys cannot be used and consequently the pistol is very heavy (11 lbs.) relative to the other makes and in addition 4 lbs of molten metal have to be handled.

Electric Spraying Pistols.—Before concluding this section on the development of the spraying processes, reference should certainly be made to experiments which aimed at replacing the gas heating by means of some electrical device, thus freeing the process from dependence upon gas supplies. The electrical method of heating permits of great concentration, or localisation, of the heat used. Schoop undertook experiments in 1914, aided this time by an electrical engineer named Bauerlin. Figs. 48 and 49 illustrate attempts to employ arc-heated furnaces for melting the metal. No material was found, however, which was capable of permanently resisting the high temperature and simultaneous abrasion of the molten metal.

Attempts were made to melt the metal by making it one pole of an arc enclosed in a small furnace, as shown in figs. 50 and 51, but similar difficulties were encountered with the hole at the bottom, the uniform dimensions of which could not be maintained. Four further attempts to solve the problem are shown diagrammatically in fig. 52.



Figs. 50 and 51.—Further Attempts to use Electrical Heating in Metal Spraying.

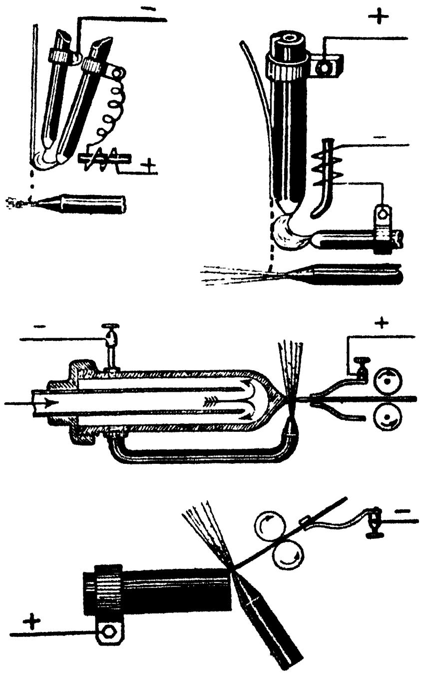


Fig. 52.—Further Possible Methods of using Electricity in Metal Spraying.

It was not, however, possible to use any of these methods in actual practice, but eventually an apparatus was constructed, on the principle

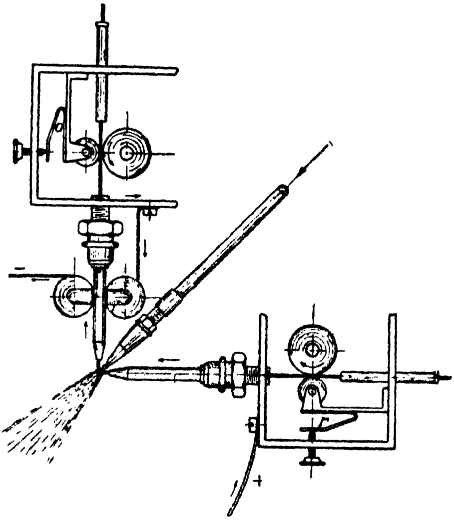


FIG. 53.—Diagrammatic View of the Apparatus shown in fig. 54.

FIG. 54.—Dr. Schoop and his First Experimental Electrically-operated Metal-spraying Apparatus.

illustrated in fig. 53, in which two wires of the metal to be sprayed were brought near one another while carrying a current of electricity at 40-75 volts. The arc formed melted the wires at their point of contact. It was difficult to arrange for the steady advance of the wires, and any irregularity tended to fuse the wire-leading nozzles or break the arc, nevertheless an apparatus was constructed to operate on these lines, as shown in fig. 54.

Fig. 55 shows another experimental model of an electrically operated wire-spraying apparatus employing a screw type of wire feed, and more approaching the handiness already achieved in the gas operated pistols.

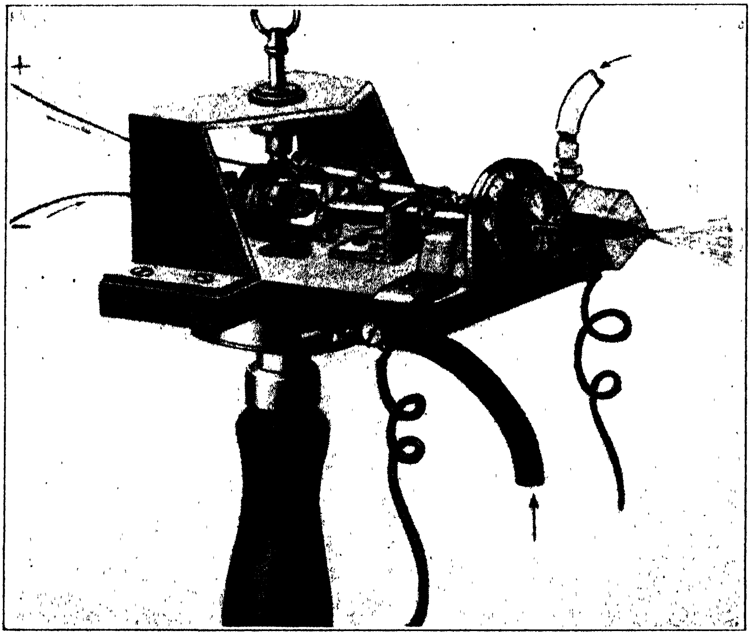


FIG. 55.—One of the First Experimental Electrically-operated Metal Sprayers ; the wire feed is operated by a screw mechanism.

A still later type is illustrated in fig. 56. Two wire electrodes are brought into contact by means of a feeding mechanism and a short-circuit is produced. The molten metal formed is blown away from the point of contact by compressed air, the pressure of which must be sufficient to extinguish the arc. When this occurs the wire electrodes are again short-circuited and the above sequence repeated. With an A.C. supply a characteristic noise is produced when the electrodes are short-circuited, but operation is quite silent with D.C. The voltage across the arc is 35-40 volts with a D.C. supply and with A.C. current may be as low as 20 volts.

The arc is very short and the flow of current is very considerable (45 amp.) so that the air in the centre portion is strongly ionised and filled with a dense mass of vaporised metal. These two latter properties tend to produce a particularly stable arc, in spite of the high velocity (300 m. per sec.) of the compressed air directed on the arc. This stability is further assisted by the small area of the electrodes, which prevents any lateral movement of the arc when once it is formed. The temperature in the melting zone possibly reaches 4000° C. and no difficulty seems to be experienced in volatilising metals such as molybdenum, tungsten and their alloys. It is stated that the particles are sufficiently hot to enable them to be melted into quartz or glass plate and form an even metallic layer which will not peel from the glass. In using the pistol some care must be exercised because appreciable ultraviolet radiation is thrown out from the arc produced between the electrodes.

FIG. 56.—Electrically-operated Wire-spraying Pistol as seen in Switzerland.

In 1924 the Spanish Company Sociedad Electro-Quimica de Flix obtained British Patent No. 210423 for an electrical circuit suitable for operating an arc pistol. The main difficulty in employing an electric arc for melting the metal used in spraying is to ensure that the arc is stable, regular and not interrupted by the powerful jet of compressed air used for projecting the spray. If it is extinguished by the air jet, then it is desirable that the arc be re-formed automatically and immediately. This was attained in the Spanish system by the use of high-frequency current superimposed on the usual alternating arc current without allowing the high-frequency current to cause trouble to other apparatus on the same mains.

The main principle of the circuit is the use of two transformers connected to the mains, one of which supplies the arc with low voltage current, whilst the other produces a high voltage current for feeding an oscillatory circuit used to generate the high-frequency current which produces the pilot sparks.

The circuit is shown in fig. 57. Transformer *a* feeds the oscillatory circuit and may be a ½ kilowatt single-phase transformer with the primary at 220 volts and 50 cycles, the secondary yielding a potential of 6000 volts. The output of this transformer is regulated by a variable inductance *b*, consisting of a U-shaped core with coils on the arms and a movable magnetic bridge between the two arms. To the ends of the secondary of *a* are connected two high-frequency chokes* which are connected to a spark gap *d* and the primary of a high-frequency transformer. One end of the secondary of this transformer is connected to the pistol and the other end to a step-down transformer *e*, which supplies the low voltage current, for example a 2 kilowatt transformer reducing the voltage from 220 to 100 volts. Condenser *f* provides a by-pass for the high-frequency current. Naturally if there was a permanent electric arc at the gap *d* no high-frequency current would be generated. Hence in front of the gap there is arranged a nozzle through which a jet of compressed air is blown on to the spark to prevent continuous arcing. The current from the transformer *a* charges condenser *g* which finally discharges across the gap *d* and through the primary of the high-frequency transformer, thereby generating a high-frequency current which flows to the pistol. The chokes *c* prevent high-frequency currents passing through the transformer *a*.

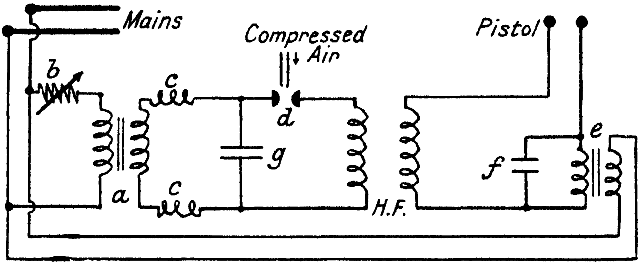


FIG. 57.—Electric Circuit of Metal Spray Pistol.

A novel method of employing an electric arc in a spraying pistol was invented by Theo. E. Bridger,† a dentist of New Zealand. The underlying

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* For those not too familiar with electricity it may be mentioned that a resistance wire only is a suitable barrier for D.C. current, but for A.C. current a coil of wire (especially when on an iron core) having negligible ohmic resistance presents a barrier which increases in effect as the frequency or oscillations per second increase. The chokes *c* offer slight resistance to the 50-cycle current but almost a complete barrier to the high-fequency current. On the other hand, a condenser forms a ready conductor of high-frequency current but prevents D.C. from passing.

† *Brit. Pat.*, 308355. 1930.

principle is the formation of an electric arc between two rotating masses so arranged as to interrupt the electric circuit. The finely powdered metal thus formed is projected by the centrifugal forces involved. Fig. 58 shows one way of utilising the principle.

The metal to be sprayed, *a*, is provided in the form of a ring held on the periphery of a hub *b*. A similar wheel *c* having a periphery of high fusing point metal, or the same metal as that to be sprayed if alternating current is used, makes intermittent electric contact with *a*. The hubs rotate at 4000-5000 r.p.m.

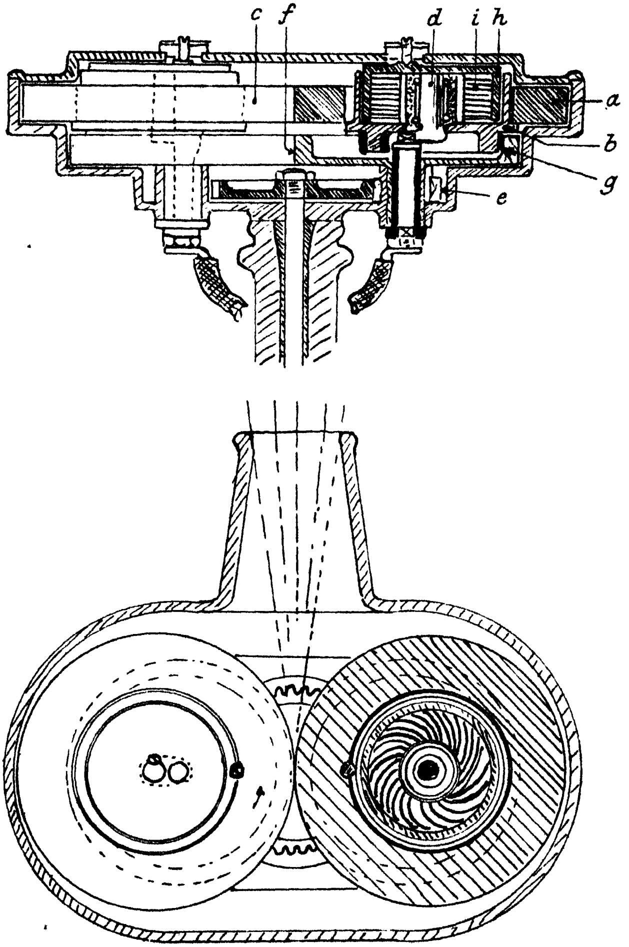

Fig. 58.—Bridger Electric Arc Metal Sprayer.

The arcing between the metal rings creates heat of sufficient intensity to cause their melting and breaking up into fine and highly heated particles which are expelled out of the arc in the line of least resistance as determined by the direction of rotation of the hubs and the magnetic repulsion.

Both wheels are free to rotate on spindles which are adjustable towards or away from each other, in order to compensate for wear on the peripheries of the bands. This is done by the use of cranked spindles *d*. The hubs can be rotated by any suitable means through gears *e*, friction drive *f* and frictional planetary gearing *g*. To cause intermittent electrical contact, the rings *a* and *c* are serrated, and the electric current is conducted through the spindles to the stationary disc *h* which is in contact with brushes *i*. These brushes consist of fine wires bent as shown in the lower diagram so that the centrifugal forces cause them to straighten and make efficient electrical contact with the disc. The hubs are in direct contact with the brushes. Suitable electrical insulation is incorporated in the machine to prevent short-circuiting of the electric current. A control mechanism allows the two wheels to be brought into contact when starting the spraying operation, but breaks contact on release of pressure, and the whole arrangement is suitably encased.

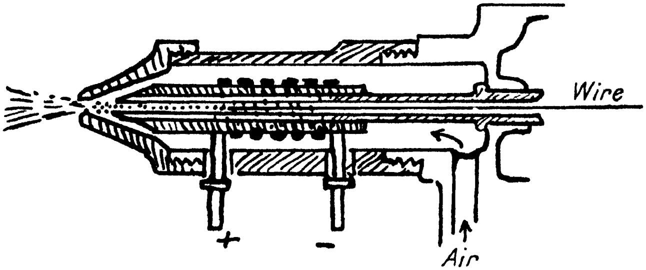

FIG. 59.—Electrically-heated Pistol for Spraying Inflammable Substances.

By the incorporation of suitable inlets, this type of construction enables the arcing to be conducted in an atmosphere of reducing or inert gases.

The spray formed in this type of electrical pistol may be classed into two groups :—

(*a*) That ejected by the explosion caused by the breaking of the arc and by the magnetic repulsion inherent in the arc. These particles are very fine and are oxidised by the high temperature reached unless a protective atmosphere is employed. It is claimed that this unoxidised spray is useful for dentistry.

(*b*) That consisting of large particles drawn out from the arc and projected by the influence of the centrifugal force. These particles can be deposited under ordinary atmospheric conditions.

Resistance Heating.—It may not be too much out of place at this point to mention another pistol designed to spray inflammable substances.* An electrically-heated tube instead of a naked flame is used for heating the material to be sprayed. The tube is wound with resistance wire or tape as shown in fig. 59.

* *Brit. Pat.*, 385857. 1933. (Schrocter.)

The material to be sprayed, for example insulating materials used in the electrical industry, may be somewhat viscous when melted and require a much greater pressure for atomising than molten metals. Two supplies of air were accordingly provided, one at a high pressure for atomising and the second at a lower pressure for driving the feed mechanism.

Electricity has been used in connection with other spraying apparatus, but the examples given suffice to show the methods followed in striving to produce handy, electrically-heated spraying pistols.

CHAPTER III.

MODERN METAL SPRAYING PISTOLS.

Wire-Spraying Process.

We turn now to consider modern metal spraying, and the unit of a large proportion of the metal-spraying processes of to-day is the wire-spraying pistol, a small, handy apparatus, weighing some 3½ lb. As has already been explained, it is possible by means of the process of metal spraying to coat any solid substance with a layer of any of the useful metals or alloys, of any thickness from 0·002 inch upwards. Zinc, tin, lead, aluminium, copper, iron, nickel, brass, bronze, etc., can be deposited in this way. Other methods of deposition, such as hot galvanising, tin-plating, and electro-plating, have their own spheres of usefulness, as well as their own limitations and defects, although, so far, the electrolytic deposition of aluminium has not been successful. Metallisation also has its own distinctive sphere of usefulness, being applicable in many cases which are barred to the older methods, and, because of this, the process is capable of wide application in the various industries.

The metal to be sprayed is introduced into the pistol in the form of wire, and is fed to the nozzle continuously and uniformly at the rate of 6 to 30 feet per minute, through mechanism operated by an air-driven turbine. Here the wire encounters a reducing flame of oxy-acetylene or oxy-coal gas, and is melted at a rate equal to the amount of feed. Under these conditions the end of the wire is melted a drop at a time, and each drop, at the instant of formation, is met by a blast of air at 40 to 50 lb. pressure, converted into a spray, and shot out in a diverging cone, having a core of reducing gas and a surrounding sheath of air.

British Wire Pistol.—The functions of the wire pistol are (*a*) to regulate automatically the speed of the wire being used, (*b*) to melt the wire, (*c*) to atomise the liquid metal.

The mechanical details of the British metal spraying pistol can be followed by reference to figs. 60 and 61, where the arrangement for feeding the wire to the nozzle will be clearly seen. Part of the compressed air supply, the quantity of which is controlled by means of a screw valve on the side of the pistol, passes into the chamber A, which contains a small aluminium turbine. The turbine rotor is carried on ball-bearings and runs at from 12,000 to 40,000 revolutions per minute, the actual speed being regulated by means of the air control valve. The worm B, formed on an extension of the turbine rotor shaft, drives a worm wheel keyed to the shaft C. The pinion D on shaft C drives the gear E, the shaft of which is mounted in bearings in a hinged bracket that can be swung back as shown. The end of this shaft is squared and accommodates the pinion F. With the shaft swung back to the position shown, this small pinion may be immediately withdrawn and another substituted when it is required to feed wire of different diameter. Depending upon the pinion which is being employed, the drive is taken to

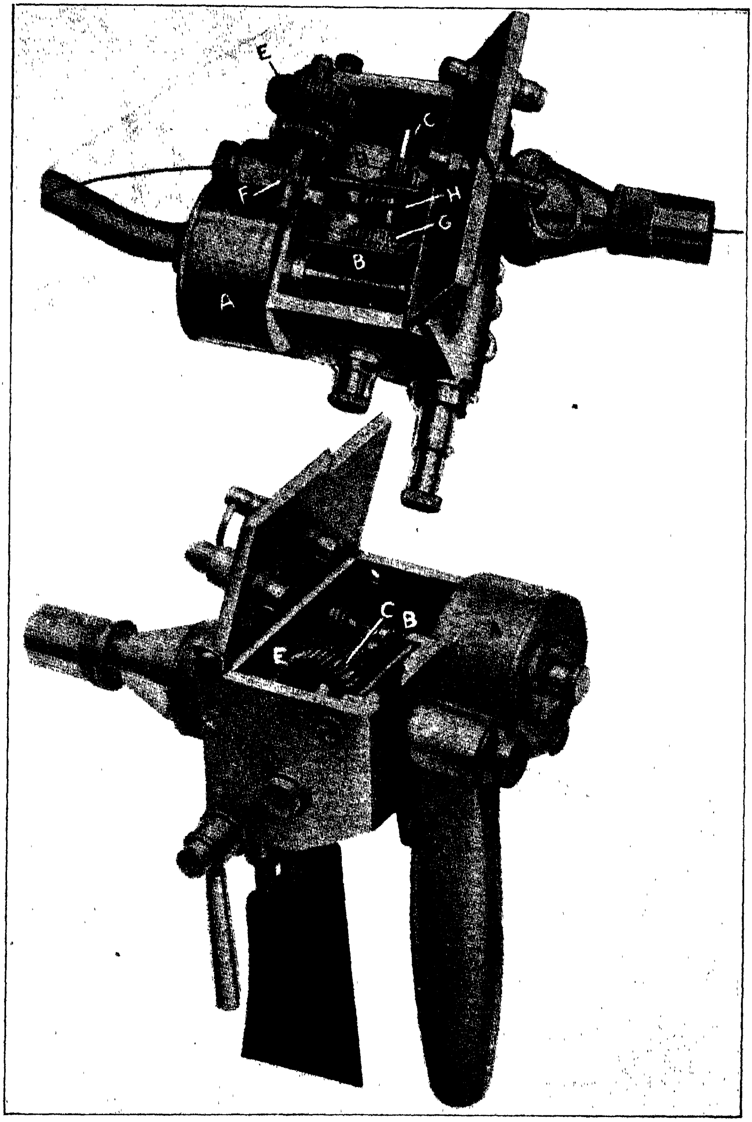

FIG. 60.—General Views of British Wire-fed Pistol.

one or other of the two gears indicated at G. These gears are carried on a sleeve which is free to rotate on the shaft C.

This sleeve also mounts a third gear H and a serrated roller for feeding the wire. The gear H meshes with a gear of equal size which, together with a second serrated roller, is carried on a sleeve freely mounted on the hinged shaft.

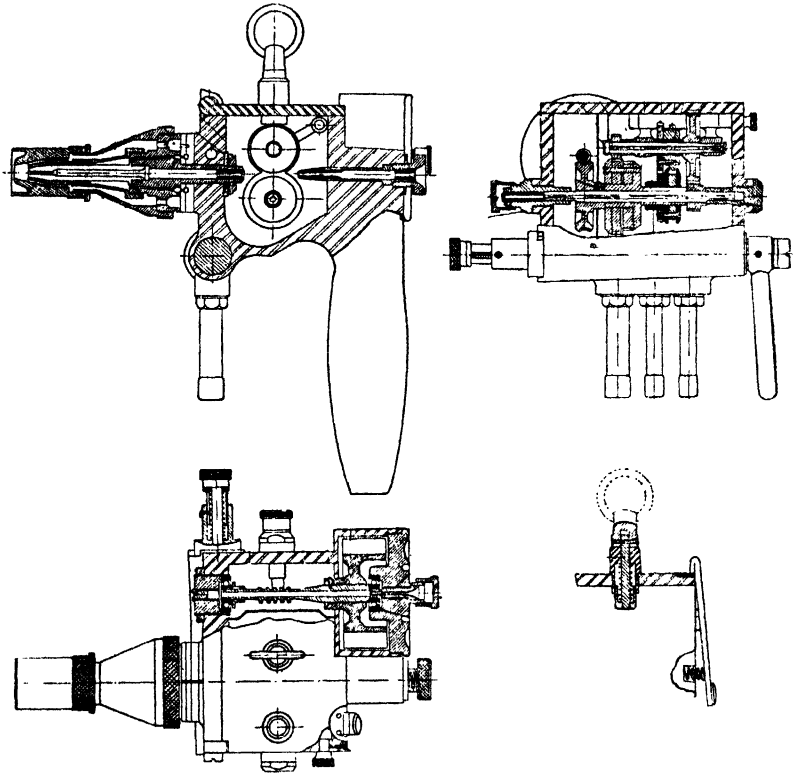

Fig. 61.—British Wire-fed Pistol, in Section.

When the hinged shaft is swung down into position the wire is gripped between the two serrated rollers, which are positively driven at equal speeds. Two rounded studs extend through the hinged cover of the pistol and ensure that the gears on the hinged shaft cannot be swung out of mesh with those on the main driving shaft when the pistol is in use.

The exhaust air from the turbine passes into the gear chamber and escapes thence into the atmosphere. The details of the valve and gas plates are similar to those shown in figs. 34 and 35.

For jobs of large area requiring a thick deposit of metal, the pistol can be fitted with a special high-speed nozzle which handles 2 mm. diameter wire without an appreciable increase in gas consumption. For this work the pressure of the compressed coal gas and air should not be lower than 28 and 45 lbs. per sq. in., respectively. Large diameter wires are much stiffer than the standard material and difficulties in feeding sometimes arise.

British "Mark 16" Pistol.—At the time of going to press, a new design of British wire-fed pistol, known as "Mark 16," is about to be marketed. It has been designed with the object of improving the purity and soundness of the deposits, at the same time maintaining economy with a high rate of deposition. The output from the 2 mm. wire nozzle was considered satisfactory, but radical changes have been made to get a robust flexible design of the other parts of the pistol, as detailed below.

The turbine has been enlarged (4 in. dia., ½ in. width) to give adequate power without excessive consumption of air and the turbine case does not project from the body of the pistol. The range of speed of the turbine is sufficient for commercial purposes without the necessity of changing gears. The two worm gears are mounted on a chassis which can be removed as one unit. Wear due to the metal shavings is prevented by sealing the gears in a grease bath, separate from the wire feed rollers, which are horizontal and mounted on spindles, the distance between their centres being adjustable from the outside of the casing. The wire can therefore be changed without opening the lid. The tension on the wire can be controlled by a screw in the case to suit soft or hard wires.

The gas supplies are controlled by three plug-type valves housed in one block, separate from the pistol case, and the valves can therefore be replaced readily. At the same time the difficulty of grinding-in a long taper valve with risk of leakage from one orifice to the other is obviated (see fig. 67). The lever control of the valves is replaced by a push bar operated by the thumb or forefinger. The pistol is fitted with gas plates the area of the holes in which can be varied by means of grub screws, and this enables a different gas to be used without dismantling the nozzle assembly. To prevent burning of the nozzle its end is tipped with Nichrome.

The hollow handle is arranged for comfort and balance and the exhaust from the turbine passes down it, away from the work; the chilling effect of the air on the operator's hand is prevented by a suitable insulating grip.

The following notes regarding the adjustment and operation of the English pistols may be of interest:—

(*a*) **Fitting of Piping.**—Before fitting the piping, pass a current of air through the pipes in order to clear them from dust. Before fitting the pressure gauges to the cylinders, loosen the adjusting screw on regulator and blow off gas momentarily, to clear the cylinder adapter from dust or other dirt.

(*b*) **Fitting Pipes to Pistol.**—The connecting pipes on the pistols are marked to distinguish them and so aid correct connection to the supply mains.

Test each pipe independently for leakages and also for clear passage of the gases. Observe for normal working pressures. Test all joints carefully with a light; also test mixing plates and chambers. Leakages in mixing plates and nozzle joints must be remedied by grinding with very fine emery powder and oil.

Compressed air must be dry and free from oil vapours; pressure 40-50 lb. per square inch.

(*c*) **To Start the Pistol in Operation.**—In order to use the pistol the lid is opened by pressing on the spring lever and the hinged bracket is swung out of the pistol case.

The metal wire is next gently inserted in the opening over the handle and pushed through until about 1 inch of wire appears through the nozzle. This is bent round at right angles. The pistol valve is then opened by turning the valve handle through 90°. The turbine is thus set in motion by the compressed air. Through the pressure of the pistol lid after the hinged bracket has been swung back, the transport rollers are engaged and the wire is drawn forward evenly through the nozzle. By opening the lid the wire can, at any time, be stopped and drawn back to the proper place.

The wire speed is regulated by a forward or backward turn of the knurled screw at the other end of the valve, and as this works to quite wide limits the adjustment of speeds is quite easy. Moreover, at the right-hand end of the hinged bracket gears is a small toothed wheel which also helps in the speed adjustment.

After having correctly adjusted the wire speed to the maker's figures, the next thing is the regulating of the melting flame.

To do this the pistol valve is opened and the oxygen regulator screw is opened, also the outlet valve screw. The cylinder valve is then opened by turning the key and the pressure on the low pressure gauge adjusted to that given on the tables. The oxygen regulator and cylinder screws are right-hand.

In the same way the acetylene pressure is adjusted ; the screws will be left-hand in this case. Care should be taken to prevent damage to the regulator by suddenly opening the full pressure of the cylinder when the regulator screws are screwed down. These should all be screwed out when opening cylinders. The pistol valve is shut by drawing up the valve handle.

The small by-pass flame is now lit at the front of the nozzle and this will burn although the pistol valve is shut. By shutting down the pistol lid the wire feed mechanism is put into operation and the wire is drawn into the pistol. By opening the valve, the supply of gases and compressed air is released, and thus the full flame is produced. The pistol is then in operation.

The actual atomising of the metal wire takes place one or two mm. in front of the wire nozzle. For this reason it is necessary to regulate the flow of gas and metal wire so that the right melting place is obtained.

If the wire speed is too low or if there is a stoppage in the feed of the wire it may happen that the wire melts in the nozzle and burns fast in. It is then necessary to increase the speed of the wire to the speed given in the table and make the necessary regulations so that the right point of melting, *i.e.* 1 or 2 mm. from the nozzle opening is obtained.

It is possible to build up the coating to any desired thickness. Obtaining a coating of uniform thickness offers no difficulty after a little experience.

The stopping of the pistol is done by quickly shutting off the valve. In order to prevent imperfectly atomised metal from falling on the work being treated, it is advisable to turn the pistol away when shutting off.

By screwing down the outlet valve screws of the regulators the by-pass flame is extinguished.

The regulator control screw is then screwed back to prevent damage to the gauges when the pistol is next started.

(*d*) **Method of Spraying.**—Spray on to the surface of the work as perpendicularly as possible, the extremity of the nozzle being kept from 3-4 inches from the surface of the work. When metallising articles which would be adversely affected by the heat of the spray jet, such as cloth, ebonite, etc., it is advisable to hold the pistol at a greater distance from the object. The correct distance of holding the pistol from an object is soon recognised. By a careful adjustment of the wire speed mechanism by means of the turbine valve as fine a spray as possible should be obtained. Every care should be taken not to handle the sand blasted surfaces or allow any grease whatever to form on them prior to spraying.

(*e*) **Lubrication.**—It is advisable each day, before starting up, to lubricate the mechanism of the pistol, and to repeat the lubrication a second time during the day.

(*f*) **Possible Troubles.**—In the following tables is given a list of the difficulties which the operator may experience in working the pistol, the probable causes, and the remedies to adopt.

Difficulty.	Cause.	Remedy.
1. On opening the valve, the flame goes out.	(*a*) Stoppage of gas passage owing to dirt, oil, etc.	(*a*) Nozzle body taken adrift and cleaned.
	(*b*) Obstruction of the gas stream through breaking, or damage to the pistol hose.	(*b*) Attend to gas tubing.
	(*c*) Wrong gas pressures.	(*c*) Correct the gas pressure by the table.
2. The flame goes out during spraying.	(*a*) (*b*) See *a* & *b* under 1, above.	(*a*) (*b*) As stated above.
	(*c*) Reduction in the supply of oxygen or combustible gas owing to insufficient pressures, due to emptying of gas cylinders.	(*c*) Check the pressures on the gauges and ensure supply is correct.
3. Melting flame enlarges during working and the wire no longer is carried forward.	Compressed air has stopped.	Stop pistol working immediately by shutting off gas cock until compressed air has been arranged for at required pressure and volume.

Difficulty.	Cause.	Remedy.
4. Interruption of the feeding of the wire.	Cracks or badly crushed places in the wire.	Wire carefully unspooled and it is best to draw through a die. If the damage is serious it is better to reject the wire.
5. Wire is drawn too slowly forward and does not pass through the pistol at sufficient speed.	The driving gear in the pistol is running too stiffly.	Take gearing out clean and grease.
6. The metal is not dispersed in sufficiently fine particles. Larger drops or small pieces of wire are thrown on to the working surface.	Speed of wire too great.	Melting flame rightly adjusted, gas pressures checked and the wire speed reduced.
7. Wire burned fast in the nozzle.	(*a*) Excess of oxygen in the flame. (*b*) See under 4. (*c*) Wire nozzle badly worn. (*d*) Mechanical defect in gearing.	(*a*) Reduce the oxygen pressure on the reducing valve. The wire that is burned in the nozzle is removed and the obstruction in the nozzle cleaned out by cautiously using a 1·2 mm. drill (larger nozzle 1·7 mm.). (*b*) as under 4. (*c*) (*d*) } Fit new parts.
8. When starting a cracking noise occurs and the flame does not persist.	(*a*) Obstruction of gas tubes. (*b*) Defective fitting of mixing plates giving intercommunication of gases and compressed air. (*c*) Excess of combustible gas over oxygen.	(*a*) Attend to gas tubing. (*b*) Plates should be ground in with very fine emery and nozzle adjusted for close fitting. (*c*) Attend to gas pressures.

Interruptions may occur with the metal-spray pistol as with any other machine, but with care and good treatment these can be reduced to a minimum. The more truly the workman handling the pistol realises that the whole apparatus is a delicate piece of mechanism and the more he respects it, the fewer will be the difficulties which he must encounter. We differentiate between two kinds of stoppages with the wire-spray pistol—*firstly,* interruptions of a purely mechanical nature, and, *secondly,* those caused by improper relations between the means of working it: air, gas, and oxygen.

Let us consider, firstly, the former of these two groups. As was mentioned earlier, the turbine shaft runs on ball-bearings, one of which is adjustable; from time to time, naturally, the whole apparatus must be cleaned, and if while doing this the turbine has been removed, it is possible to replace the turbine shaft either too loosely or too tightly, whereby the bearings will naturally suffer either by wearing too rapidly or by tending to seize. The turbine shaft should be so fitted that it has practically no play although running quite freely. Should it occur that during operation the feed suddenly shows such variations that work cannot be continued, then it is necessary to see whether a ball has broken and caused a seizing in the bearing or on the shaft. If the damage is only slight, one can polish up the race or the shaft with emery paper, but if it is badly damaged it must be replaced. Defective, broken, or misshapen balls should always be replaced. If the turbine bearings have been freshly lubricated the turbine should be run light for a time until the normal feed is established. The adjustable friction bearing of the middle shaft, intended to take up axial pressure, should not be moved unless absolutely necessary. If it is for any reason necessary to move it, and if in so doing one has not left an equal amount of play to the worm wheel to right and left, then heavy work may lead to sticking. Since the gear in the middle shaft has to take a fairly high pressure, it must never run dry; if the oiling be once overlooked, the seizing of the bearing will cause a stoppage, or, at least, slower running. If a pistol has been long in service, especially when much hard metal has been sprayed, it sometimes happens that the wire slips in the transport rolls and is no longer pushed forward by them. This is easily recognised in operation because the wire simply stops and no more metal is sprayed; if the edges of the transport rolls are badly worn, new ones must be fitted. Stoppage of the feed may also occur when working if the wire has sharp bends in it or has been crushed and no longer conforms to the specified dimensions. Further, stoppage may occur, especially with soft metals, if the feed is set very slow. The wire is not fed at all or, at any rate, only partially if the feed rollers or the gear wheels do not correctly engage with one another; this should be ensured before closing the cover. According to the nature of the material of the springs, it can happen that after a certain period they become slack, the wire is then no longer pressed sufficiently forcibly against the feed rollers, whereby slipping may occur; the spring must then be replaced by a new one. It frequently happens in spraying soft metals that through the sliding in the wire leader small chips of the wires are scraped off, and in time these collect in the wire tube or are even forced into the front; they reduce the opening and finally stop the passage of the wire. This kind of interruption is characterised by the fact that the wire does not stop at once but is still pushed forward from behind until after the feed has fallen off very much, when it finally stops entirely. The occurrence of this stoppage is best prevented by cleaning the wire tube from time to time. In order to stop the scraping of the wire in the wire tube or to reduce it with the soft metals, lead, tin, and zinc, it is advisable to slightly oil the wire, and this is best done when winding it on the reels. If the opening in the wire tube has been enlarged too much, this can also cause interruption; the worn wire tube must then be replaced by a new one. Such are the stoppages which can occur through purely mechanical causes.

As regards the second group, it should be first remarked that under all circumstances air must be prevented from getting to the gases before they leave the gas tubes, and similarly the two gases, combustible gas and oxygen, must not be allowed to mix before they arrive in the mixing chamber between the two baffle plates. These conditions are only fulfilled if the cock, baffle plates, nozzle head, and gas tube are all perfectly gas-tight. Should it, for example, occur that on opening the cock, when starting the pistol, the flame is always blown out before the valve is fully opened, then a leak is indicated, assuming, at any rate, that the cap of the air tube is fixed on to the gas tube. In such a case it is necessary first to ascertain whether the flange of the gas tube is damaged; if this is so it must be carefully polished on a smooth surface such as a glass plate, by means of emery paper. If, when the gas tube fits abolutely tight on the nozzle head (the gas-tight surface of which is to be treated in the same way as that of the gas tube), ignition of the flame is still not possible, one must see whether the cock has become leaky either on account of the screw having loosened or because it has been damaged when taking it out. The investigation is conducted as follows: The two gas tubes are moved from the reduction valves, and the ends held in a vessel of water, the air is now admitted to the cock which is in the closed position. If the cock is not gas-tight from the air hole to one or the other of the two gas holes, air can get into the gas tubes; this is detected by bubbles escaping into the water. Gas leaks need not always occur along the whole length of the cock, it can also happen that the air is entirely shut off while between the two gas passages leakage occurs so that the gases mix in the cock itself and thus cause a stoppage of the apparatus. To test this one must connect up either the hydrogen or the oxygen once more and admit it to the cock; the other gas tube is held in water to detect bubbles. If in these tests leakage is observed at the cock, the latter must be ground in with fine emery dust. In doing so, very little emery dust must be used; in any case the polishing of the cock in this manner is only to be done in case of extreme necessity, *i.e.* when it is actually so leaky that the pistol will not work. After grinding-in, the cock should be cleaned with benzine and then greased. With the stop-cock now in order the pistol should work satisfactorily again; if, however, the flame goes out on starting up (frequently with a bang) the following procedure must be adopted. The two gas tubes are connected with a manometer, the other remaining on the reducing valve while the gas lead is closed. One now opens the cock, allowing the air to pass out, and simultaneously takes the reading of the vacuum meter. If it does not show the vacuum prescribed for the particular nozzle, but considerably less, or even a pressure, then this is a sign that air can still somehow get to the gas. Since all the gas-tight surfaces are good, the trouble can only lie in the surfaces of the baffle plates or in the casing. The nozzle head is therefore unscrewed and the gas-tight surfaces behind this are examined and the baffle plates as well as the surfaces on the casing ; any damage to these surfaces must be removed by polishing. The small holes should be well washed out before assembly, and care must be taken that nozzle head and baffle plates come back exactly to the same spot. Finally, it may be pointed out that the thread of the gas-tube cap can also leak, either on account of much wear or because the cap is drawn up insufficiently tightly against the wire tube.

It is advisable to lubricate the thread from time to time with a little grease. If all these tests have been carried out with care, the pistol will undoubtedly work satisfactorily. Should the flame become smaller when spraying, or if large grains may be seen in the coating in spite of constant feed and the required air and gas pressures being maintained, then the gas passages in the baffle plates have become stopped up. This occurs especially with new plants at the beginning of operations, because the gas always carries out of the new piping a certain amount of dust which collects in the small capillaries. The baffle plates must then be taken out and cleaned, but in no case must this be done in such a manner as will increase the size of the capillaries. Some metal always adheres to the wire and gas tubes after a time, especially when much soft metal has been used ; this is, in general, not of any great importance, but can easily interrupt operation. If on this account the flame does not remain central, due to metal accumulating in the tube, the nozzle must be cleaned, and it is then also advisable to rub the ends of the wire and gas tubes with graphite, this hinders the adhesion of metal. It may still be added that to avoid difficulties in operation, the prescribed air and gas pressures must be accurately maintained. The air pressure recommended may on no account be altered ; but in the case of the gas pressure, if satisfactory results cannot be obtained, it is permissible to slightly increase or decrease the pressure. In regulating the gas supply it should be noted that too great an excess of the one gas, especially of oxygen, should not be present, otherwise the flame becomes explosive and blows out or the intense heat may readily attack the wire

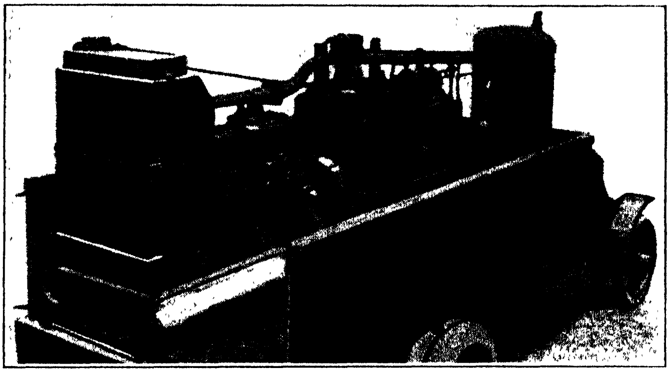

FIG. 62.—Mobile Metal-spraying Plant.

tube and damage it. Further, when increasing the gas pressure, the hydrogen pressure must always be increased first and only then the oxygen. When reducing the pressure the opposite procedure is followed, *i.e.* the oxygen is reduced first.

The same holds in relation to opening and closing the gas supply on commencing or at the termination of the work ; on beginning, the hydrogen is first admitted and only then the oxygen, while, when finishing, the oxygen is first shut off and then the hydrogen.

To apply the metal coatings, both fixed and movable plant may be employed, the design in each case varying with the character of the work to be treated. For outside work, or to meet cases where neither compressed air nor gas are available, complete portable or mobile plants have been designed and are used both in this country and abroad. An example of such a mobile metal-spraying plant is illustrated in fig. 62. This consists of a motor lorry permanently fitted with sand blasting apparatus, a crude oil engine and air compressor, together with the necessary gas cylinders and other loose equipment. The air compressor illustrated is capable of delivering 160 cubic feet of air per minute, and travels set up in the lorry to the field of operations.

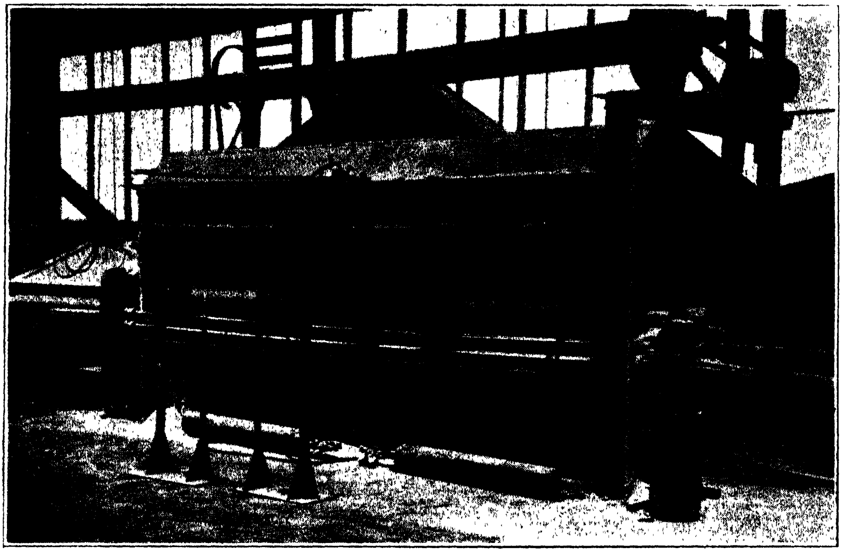

FIG. 63.—Machine for Spraying Cast-iron Pipes with Lead as a Protection against Certain Chemicals.

Internal and External Pipe Sprayers.—A machine is being operated in one works in this country which uniformly sprays with lead the outside of long metal pipes for use in the chemical industry. This may be seen in fig. 63. It sand blasts and sprays the tubes with very little manual assistance. A machine built on the lathe principle is also used, in which tubes or rolls are mounted for spraying and rotated between centres, whilst a pistol carried by a slide rest is traversed along and metallises the surface.

By mechanical means, such as that described above, the thickness of the metal coating can be gauged with accuracy, and even with limited experience of hand-spraying there is no difficulty in applying a coating to specification. Any thickness up to, say, ⅛ inch can be applied, the governing factor being time.

The Rotary Nozzle is suitable for coating the bore of tubes 1 to 3 inches in diameter. Above 3 inches diameter the metal is not thrown far enough to ensure a satisfactory coating. The nozzle can still be used on large diameters, however, for applying a thin coating which can be used for building-up worn or oversize housings which have to take a forced fit liner or bearing.

It has not been successfully used for spraying low melting point metals such as tin or lead due to the fact that a much larger quantity of metal has to be deflected than with high melting point metals. This causes stopping of the rotating nipple.

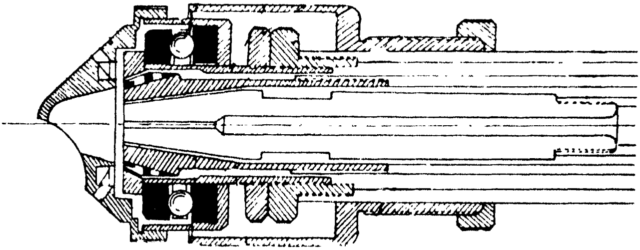

Fig. 64.—Rotary Nozzle in Section.

It does, however, work satisfactorily with all higher melting point metals such as aluminium, copper, zinc, bronze, iron, etc.

The rotary nozzle is lighted in the same way as the standard nozzle, but with a sharp jerk of the valve lever, so that the nipple starts spinning immediately.

Fig. 64 shows the construction of the spraying end of the rotary nozzle. The deflection nose-piece is carried on a thrust bearing and is rotated by the impinging of the air blast.

Extension and Deflector Nozzles are illustrated in fig. 65. The former can be used for an intricately shaped job which cannot be properly coated with the ordinary nozzle ; it consists essentially of an extension tube fitted to a standard pistol. Extension nozzles vary from 1½ to 4½ feet in length.

The deflector nozzles can be used where the diameter of the tube is too large for the rotary nozzle. An angle nipple can be fitted to the extension tube so that the spray is deflected at about 45°. This construction is suitable for high melting point metals, but the most useful nipple (fig. 65) is so designed that an extra jet of air deflects the original spray. To compensate for the air used in this manner, an extra supply is added by means of valve A at a pressure of 45 lbs. per sq. in.

Fan Spray Nozzle.—The ribbon of metal sprayed with a standard nozzle is always thicker in the centre and each ribbon has to be overlapped.

The fan spray nozzle (fig. 66) has been developed in America to enable more uniform layers to be sprayed. Two jets of air, diametrically opposite to each other, impinge on the atomised stream of molten metal issuing from the central orifice and a spray is formed similar in shape to the flame from a bats-wing burner. A wide thin ribbon or a narrow thick ribbon can be sprayed.

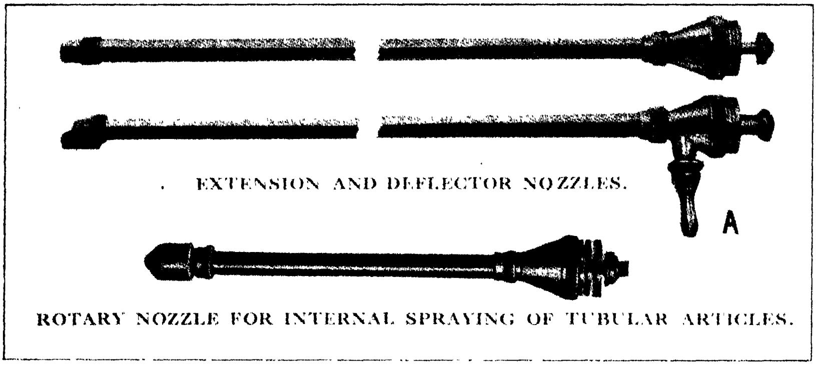

Fig. 65.—Miscellaneous Nozzles.

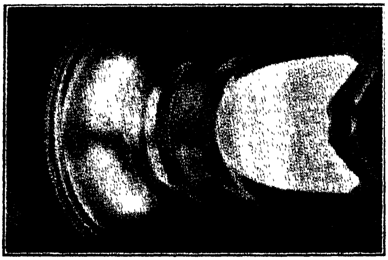

Fig. 66.—Fan Spray Nozzle.

Other types of Wire-fed Pistols.—(*a*) *French.**—The construction of this pistol is illustrated in fig. 67, from which it will be seen that the main differences from the English pistol are : (*a*) In the use of worm gears throughout and the sealing of these in an oil bath. This is an effective arrangement in the new instrument, but after dismantling for repair the joint is sometimes imperfectly made up, with the result that oil leaks occur. (*b*) In the use of three separate valves operated by gearing from a single lever. Leakage is thus minimised. (*c*) In the use of a special nozzle† designed for using acetylene. An extra air cap allows the air blast to arrive at the flame zone

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* Marketed by the Société Nouvelle de Métallisation.

† *Brit. Pat.* 202604, 1924.

in two stages, and the gas nozzle is also set slightly in advance of the wire nozzle. The advantages claimed are that the metal is melted out of contact with the compressed air; economy; and striking-back of the flame into the ducts supplying the combustible gases is obviated.

The English pistol has no extra air cone and the air arrives at the flame zone at a smaller angle to the wire axis than is the case with the French pistol. The American pistol to be described next has no extra air cap and the air angle is smaller than in the English pistol.

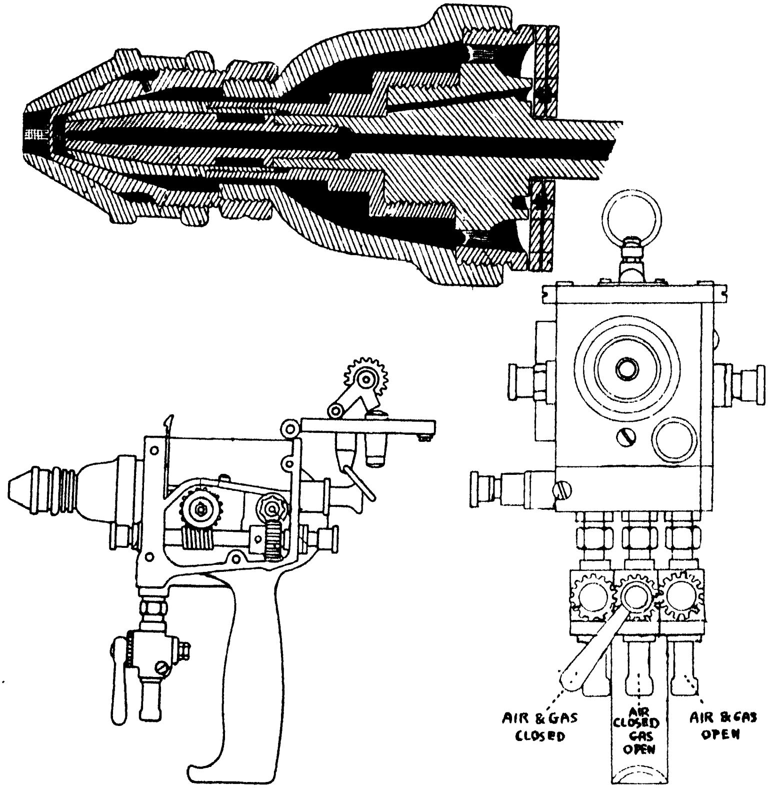

Fig. 67.—French Wire-fed Pistol.

(*b*) *American.*—Two pistols are in use in America, one type, Y, fig. 68,* being similar to the English tool, with the exception of the nozzle arrangement and the use of worm gears throughout. So-called "3 in 1" features are claimed due to the fact that the pistol is available in three gear reductions and the change-over from one gearing to another can be accomplished in a few minutes. These gearing combinations, together with variations in turbine speed, make possible a wire feed speed range of 2 to 40 feet per minute.

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* Marketed by Metallizing Company.

Besides its use as a standard all-metal unit, the pistol can be adapted either as a high-speed unit on low melting point metals or as a hard metal unit specially for high-speed work on the higher melting point metals, such as carbon steels, stainless steels and nickel. The combustible mixture is arranged to give high thermal efficiency and consequently the sprayed metal can be somewhat oxidised under certain operating conditions.

The second type of American[*] pistol is shown in fig. 68, X. A good balance is obtained by passing the gas connections through the handle and the knurled rolls for feeding the wire are not enclosed with the gearing. This has the advantage of preventing " wire shavings " getting into the delicate working parts. The air from the turbine exhausts on to the operator's hand and does not add to his comfort. The heavy gauge wire (⅛ in. dia.) used necessitates a large flame, and care has to be taken to prevent overheating of the article being sprayed.

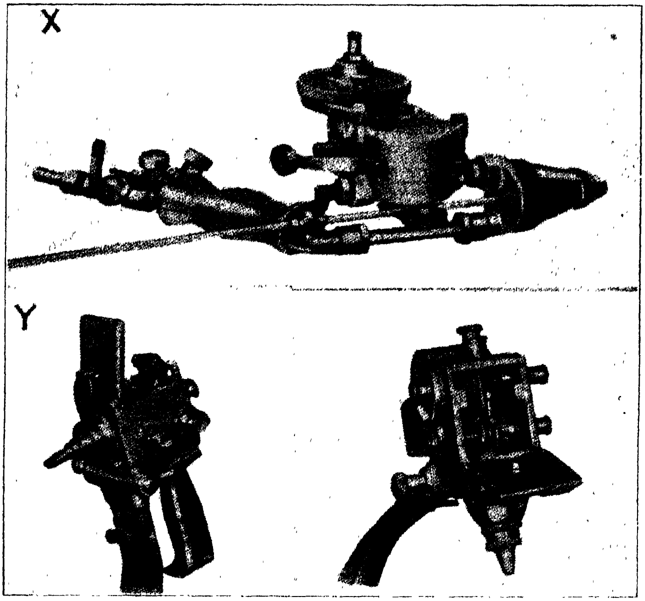

FIG. 68.—American Types of Pistol.

Reference should also be made to the Mogul pistol recently marketed[†] as a building-up tool for steels, nickel and copper alloys and aluminium. This very rugged pistol, 5½ lbs. in weight, is shown in fig. 69. A large air turbine drives the wire feed rollers through worm gearing which is completely enclosed in an oil bath and protected from both wire shavings and gases. The nozzle is fitted with a single valve, operating all three gas ports and also

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[*] Marketed by Metal Spray Company.

[†] Metallizing Company of America.

arranged so that the pistol can be lighted without wire in the nozzle, a feature which makes possible the spraying of rods ⅛ inch diameter, although 11 (B. & S.) gauge wire is commonly used. Two models are made, " A " geared for spraying steel and similar high melting point metals and " B " for spraying aluminium and copper. Both models can be provided with a hand grip and tool post attachment. A special model with an aluminium head, weighing 4 lb., has been developed for hand operation.

When spraying flat surfaces the pistol is held 7-10 inches from the object, while for coating shafts the distance is 5-6 inches, and the coating can be applied in one transverse pass of the pistol if care is taken to keep the surface of the coating cool, for example, by using an air jet on the back side of the shaft.

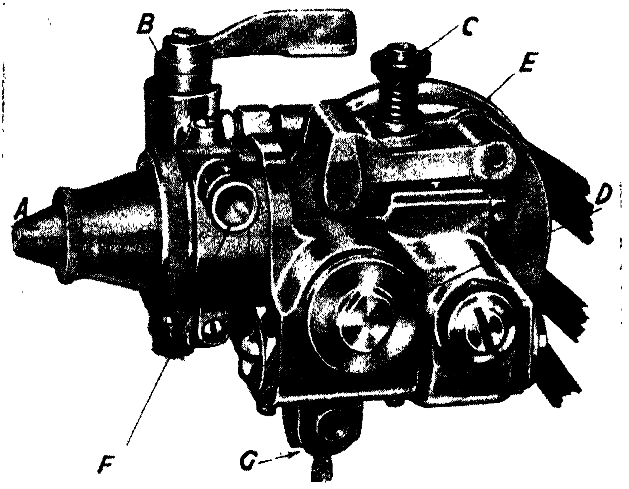

Fig. 69.—" Mogul " Pistol for " Building-up " Work.

A—Nozzle.
B—Control valve for gases.
C—Control for wire feed.
D—Enclosed gearing.
E—Turbine.
F—Valve for turbine.
G—Tool post.

It is claimed that Model " A " will deposit 6·1 lb. stainless steel, 5·3 lb. iron or 7·1 lb. high carbon steel per hour ; Model " B " will deposit 9·9 lb. copper or 4·1 lb. aluminium per hour, using 45 cu. ft. acetylene, 52 cu. ft. oxygen and 45 cu. ft. air per minute.

When using thick wire (⅛ in.), light the pistol before inserting the wire, but do not run for any length of time in this manner. The atomisation of the metal improves as the air cap is screwed out, but this should be limited to three turns, otherwise backfiring may occur. Occasionally a backfire will cause soot to deposit in the four gas holes at the front end of the wire nozzle and the pistol to backfire repeatedly. These holes should be cleaned with a suitable drill. If, when lighting the pistol, the flame is blown out with a sucking or swishing noise, it indicates too much acetylene pressure or a leak in the gas passages. If there is a report inside the air cap body and the flame blows out it means there is a leak where the wire nozzle attaches to the gas head body.

A Swiss pistol was designed by Schoop for spraying low melting-point metals in a neutral atmosphere of carbon dioxide. The wire passed through a tube fitted with fins which absorbed heat from two oxy-acetylene flames. The carbon dioxide was also heated during its passage round the fins and finally served to atomise the wire at the nozzle. It was claimed that homogeneous coatings were produced, but no extensive use of the pistol has been made in England.

Fuel and Wire Supplies.—The general arrangement of the wire pistol is shown in fig. 70. The wires used in England are of the following gauges :—

Metals	Diameter	Gears	Speed
Tin, lead, etc.	1·5 mm.	14 teeth	>20 ft./min.
Zinc (high-speed pistol) . . .	2 mm.	24 teeth	
High melting-point metals . .	1 mm.	11 teeth	>20 ft./min.

The wire is wound on spools containing about 60 lbs. of zinc, the weights of spools of the other metals varying in proportion to their specific gravities. The reels are placed on a stand and rotate freely on a spindle, fitted in some cases with ball-bearings. The turbine in the pistol will pull the wire from the spool automatically.

Fuel gases include compressed coal gas, hydrogen and dissolved acetylene, and more recently propagas. The compression of generated acetylene gas is prohibited in England, but such is used on the Continent. When using either acetylene or hydrogen, a special regulator is required having a high pressure gauge and a working pressure gauge. Coal gas can be used from cylinders, but it deteriorates during storage and its cost is almost as great as that of dissolved acetylene. Hence it is more usually obtained from the town mains through a non-return valve and compressed to 25-30 lbs. per sq. in. pressure on the site, by means of a small compressor. Two gas receivers are frequently used ; one between the gas meter and the compressor to prevent sudden shocks on the meter and the second on the output side of the compressor.

Compressed Air.—The supply of compressed air is obtainable from any standard type of compressor capable of maintaining a pressure of not less than 50 lbs. per sq. in., with a supply of 20 cu. ft. per minute. A horizontal type is usually recommended owing to there being less possibility of oil getting through to the pistol. In many cases a compressor is installed which is also capable of supplying the sand blasting equipment in addition to the spraying pistols. Air coolers are sometimes fitted to remove moisture from the air supply and they are usually well worth while, since a zinc deposit shows an improved resistance to corrosion when moisture is absent during the spraying.

Oxygen Supply.—This is usually obtained from commercial cylinders fitted with a high pressure gauge for measuring the contents of the cylinder and a low pressure gauge to check the pistol working (see fig. 70). In works using several pistols it has been found convenient to centralise the oxygen supply by using batteries of 20 cylinders, each of 150 cu. ft. capacity, carried in cradles. Pipe lines from this station are carried to various parts of the works and a master valve serves to reduce the pressure from 100 to 30 lbs. per sq. in.

Characteristics of Wire Pistols.—Wire pistols are essential for the building-up of thick deposits in salvage work and yield metal which can be almost free from contamination except oxide. Surfaces with good resistance to oxidation can be produced. Unfortunately, the wire pistol has a number of wearing parts and is not so robust as the other pistols. The cost of spraying is usually slightly greater than with the powder pistol, but an important advantage is that internal work can be sprayed.

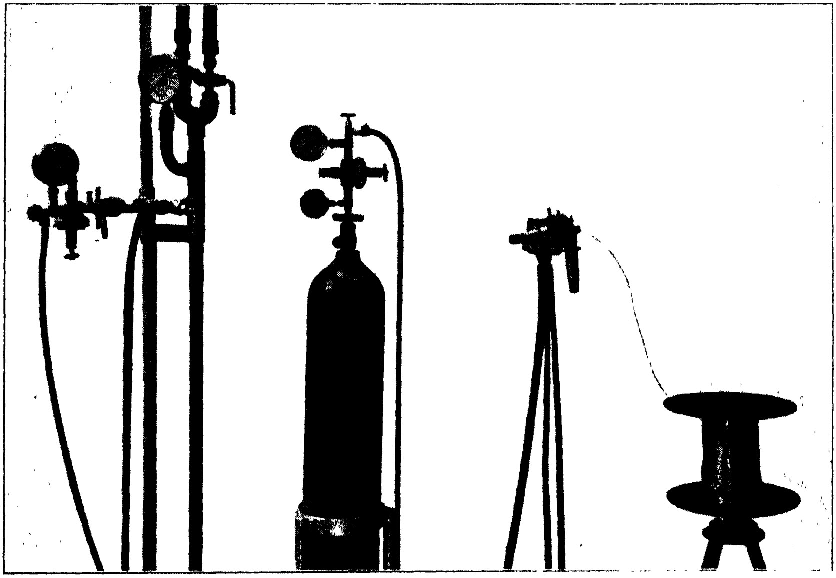

FIG. 70.—Complete Oxy-Coal Gas Metal Spraying Installation.

Molten Metal Pistol.

The construction of the modern molten metal pistol is shown in fig. 71, from which it will be seen that the essential principle is the same as in the pistol described on p. 4. It is gravity fed with molten metal held in the malleable iron container, the temperature being maintained by the flame from the Bunsen burner beneath it. The flame also preheats the compressed air, carried by a stainless steel pipe to the silver steel nozzle (0·035 inch diameter). This air pipe is coiled just in front of the burner instead of around the container, as in earlier models. This change, together with a new design of heat-resisting steel cowl, saves weight at a point where the balance of the pistol is greatly influenced. A limitation of the gravity fed pistol is the fact that overhead work is impossible, since the pistol must always be slightly inclined downwards. This has been partly overcome in a modified design, illustrated in fig. 72, in which the nozzle projects upwards and the whole instrument is made in miniature to facilitate manipulation.

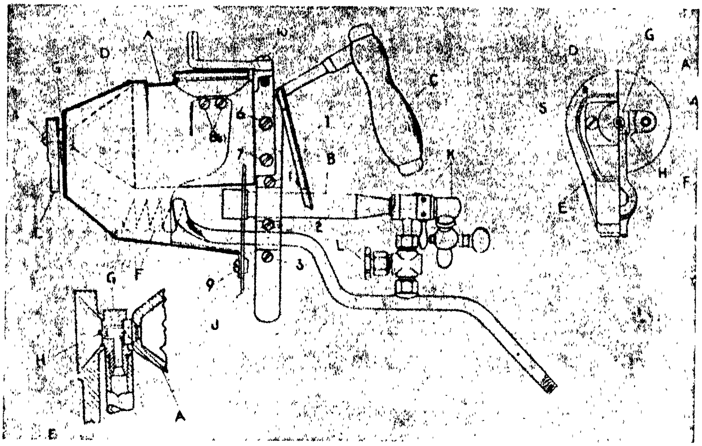

FIG. 71.—Molten Metal Pistol.

A.	Container.	G.	Air Feeder.
B.	Burner.	H.	Silver Steel Nozzle.
C.	Handle.	I.	Hand Guard.
D.	Cowl.	J.	Shield.
E.	Front Plate.	K.	Air and Gas Injector.
F.	Compressed Air.	L.	Air Regulator.

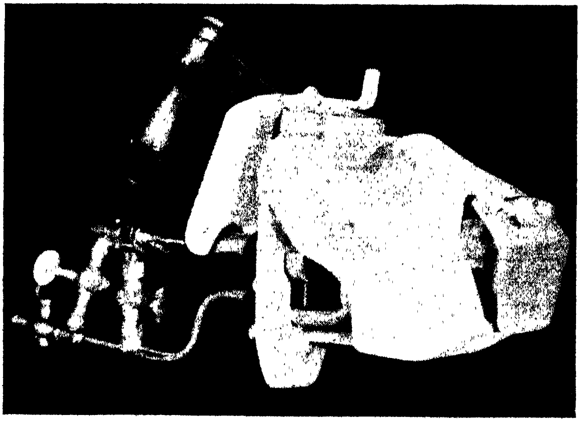

FIG. 72.—Molten Metal Pistol for Overhead Work.

One of the difficulties with the molten metal pistol is concerned with its maintenance, the silver steel nozzle and also the container being rapidly attacked by the molten metal; the former has a life of 1-1½ hours and is renewable in 2-3 minutes, although a longer time is common because the workmen make use of the time for this operation as a rest period. Refractory liners of morganite, △N, and fused corundum increase the life of the nozzle to about 13 hours' spraying time, but naturally are very expensive and frequently fail as a result of the different rates of expansion of the steel and the refractory. The same dilatation troubles were also experienced when refractory was used for the container.

The action of molten zinc on iron and steel has recently been studied by Musatti and Falce.[*] It was shown that the attack of steel by zinc increases rapidly above 480° C.; so much so that in some steels the loss at 520° C. is about five times as great as at 460° C. As regards composition of the steel, it was found that the effects of carbon and silicon are much greater than those of other elements. A carbon content of 0·5 per cent. seems to mark the limit above which steel is strongly attacked. The loss of weight of a steel containing 1·0 per cent. carbon after 8 hours' immersion in molten zinc is twenty times as great as for a 0·1 per cent. carbon steel at the same temperature. The effect of silicon seems to be more serious than carbon, because even small amounts have a marked influence. A silicon content of 0·87 per cent. caused the loss in weight to become about twenty times as great as in steels practically free from silicon. Sulphur, phosphorus and manganese, within limits, have little influence on the attack. Nickel appears to reduce corrosion slightly, but chromium seems to cause increased attack. The stainless steels show a loss of weight almost equal to that of plain low-carbon steel.

As a result of the attack of the molten metal on the material of the pistol, the possibility of contamination of the sprayed metal must be borne in mind. Micrographs of zinc coatings sprayed very close to the nozzle invariably show small string-like masses which do not etch. While these may be zinc-iron compounds owing to the solution of the container, it is highly probable that they are due to abrasion of the nozzle. They are not present in coatings sprayed at 5 inches from the nozzle and this may be due to the fact that they fall from the spray due to their weight relative to that of the zinc.

Operation.—The metal to be sprayed is melted in a small gas-fired crucible furnace of about 1 cwt. capacity, provided with an immersion pyrometer to check the temperature, ranges of which are as follows:—

Metal	Melting-point, °C.	Spraying temp., °C.
Tin	232	250-270
Lead	327	350
Cadmium . . .	321	360
Zinc	419	470-475
Aluminium-silicon	560	650

Two connections for gas at town-mains pressure and compressed air are made to the pistol, which is warmed up by the Bunsen burner. The container

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[*] *Metal Treatment*, Spring 1937, p. 171.

of the pistol is filled from a small ladle as illustrated in fig. 73. The metal charge (4 lbs. zinc) in the pistol lasts about 20 minutes, but if spraying is intermittent, during the idle periods the pistol can be rested in the rack or its contents can be emptied back into the furnace. The pistol is held five or six inches from the surface being coated, and pointed downwards slightly so that the molten metal flows to the nose of the container.

The thickness of the coating at a speed of about 5-8 sq. ft. per minute varies from 0·003 inch with a new nozzle to 0·006 inch with a worn nozzle. As the nozzle wears, the spray becomes coarser and somewhat irregular owing to irregular wear. To maintain a uniform thickness, the speed of spraying is increased as the nozzle wears. Occasionally the nozzle becomes filled with dross which has to be removed by poking with wire.

The length of projection of the nozzle from the air feeder influences the character of the spray, the fine spray being produced by the longer nozzle. Consequently, some operators file down the nozzle to produce a coarse spray when heavy classes of work are being sprayed. With a very short nozzle the spraying becomes jerky.

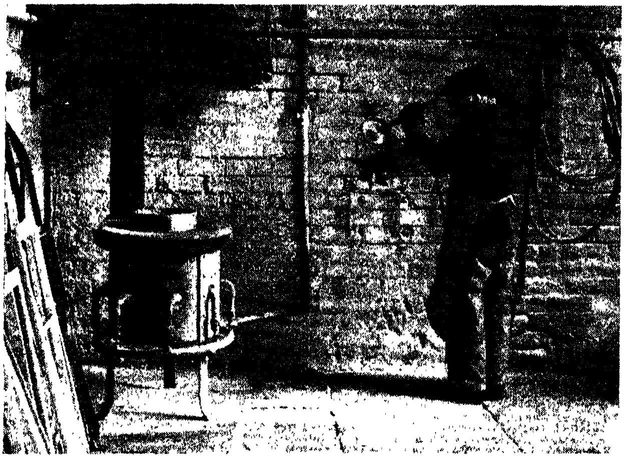

Fig. 73.—Method of Charging Molten Metal Pistol, and Furnace for Metal Melting.

Supplies.—Unlike the other processes of spraying, the molten metal pistol requires neither cylinder oxygen nor compressed fuel gases. Coal gas at town-mains pressure is required for the Bunsen and for the furnace and the compressed air supply is similar to that already described for the wire pistol. As a result of this simplification, and also owing to the use of metals in ingot form, the process is particularly suited to contract galvanisers.

Advantages and Limitations of Molten Metal Pistol.—The molten metal pistol has certain limitations: owing to its design it is possible to maintain only a comparatively low temperature with it, therefore its use is limited to the lower melting point metals. The coating of the insides of tubes is impossible and certain outside jobs are difficult to carry out.

The operator's task is not very congenial in the case of this pistol owing to the weight to be supported and the temperature of operation.

The low temperature limitation mentioned above is not so serious as might appear, since the greatest proportion of work undertaken is sprayed with zinc for protection against corrosion.

Solder Gun.—In 1935, Taylor* obtained a patent for the pistol illustrated in fig. 74. The metal is supplied in stick form and is melted by means of an oxy-acetylene flame. The air is controlled by a needle valve and also by the trigger valve shown. The pistol is primarily designed to spray solder into dents in motor car bodies, the surface being fluxed prior to spraying, and the deposit can be melted by the oxy-acetylene flame when the metal container is swung out of the way. A small 300-watt electrical heater can be used for melting the solder instead of gas.

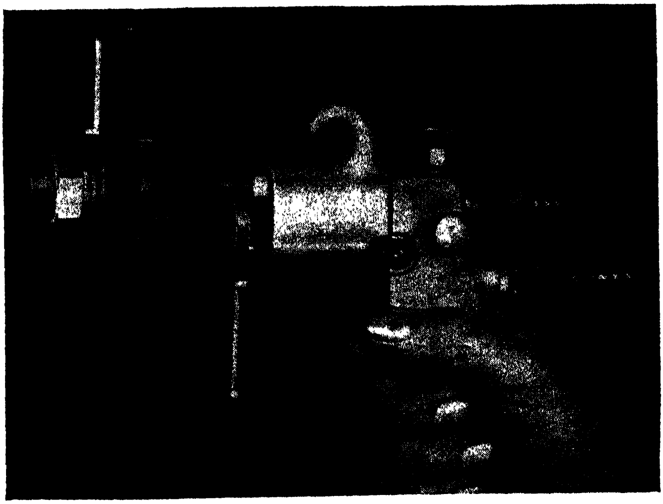

FIG. 74.—Molten Solder Pistol (Taylor Patent).

Powder Process.

Of the powder-fed pistols invented, only the Schori † has become of any commercial importance; in common with the Mellowes instrument, it has no moving parts. The powder is sucked through an oxy-gas flame and blown on to the object. The construction of the pistol is shown in fig. 75. The pistol consists essentially of two injector arrangements; one is in the handle and is similar to that found in a blow-pipe used for mixing the oxygen and acetylene or other fuel gas, at the same time preventing back-firing in the pipes, while the other, similar to a filter pump, is used for aspirating the powder from a suitable container fitted with a small vibration fan. Compressed air regulated by valve V flows

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* *Brit. Pat.*, 454044.

† *Brit. Pat.*, 432831.

into chamber G where it splits, part passing into chamber A and through the nozzle B thereby creating a partial vacuum in the pipe E connected to the supply of powder and also to the atmosphere at F in the handle, which must be covered by the operator's thumb before sufficient suction is created to aspirate the powder. The metal powder passes through radial holes D and is carried along by the compressed air through the central tube K. As it is ejected from the gun it comes into contact with the oxy-acetylene flame. A quantity of air from chamber G passes through orifice H, issues at the elliptical space, shown in section ZZ, surrounding the circular flame, and projects the fused particles on to the object being sprayed.

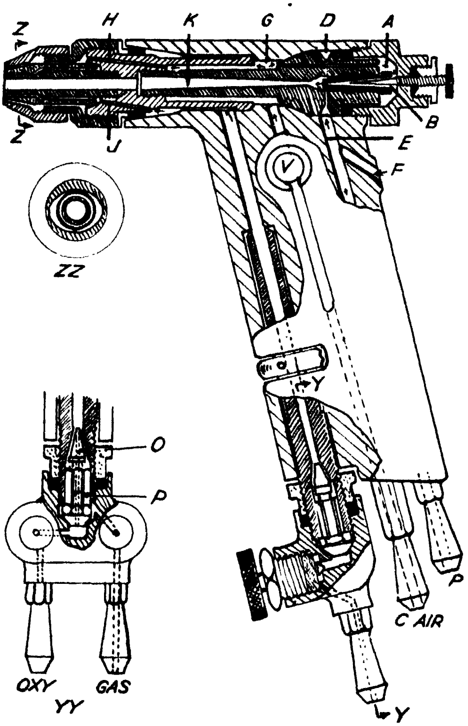

Fig. 75.—Schori Powder-fed Pistol.

The oxygen and acetylene employed for the flame enter at the bottom of the handle and pass through needle valves which can be regulated to control the temperature. In the French Schori pistol plug valves are used. The acetylene passes through the grooves P and the tapered extension tube which serves as an expansion chamber. The oxygen likewise passes through the central hole O to the tapered tube where it mixes with the combustible gas. The mixture flows through the holes J to the nozzle, where it is ignited.

This arrangement of parts provides a handy and well-balanced pistol which is made in different sizes.

The general arrangement of the Schori pistol and connections is shown in fig. 76. A high pressure acetylene generator is used on the Continent, but in England this is replaced by a cylinder of dissolved acetylene or by a ferrolene equipment. The latter is a very suitable means of providing a fuel gas, and consists in enriching coal gas with hydrocarbons, and compressing to 7 lbs. per sq. in.

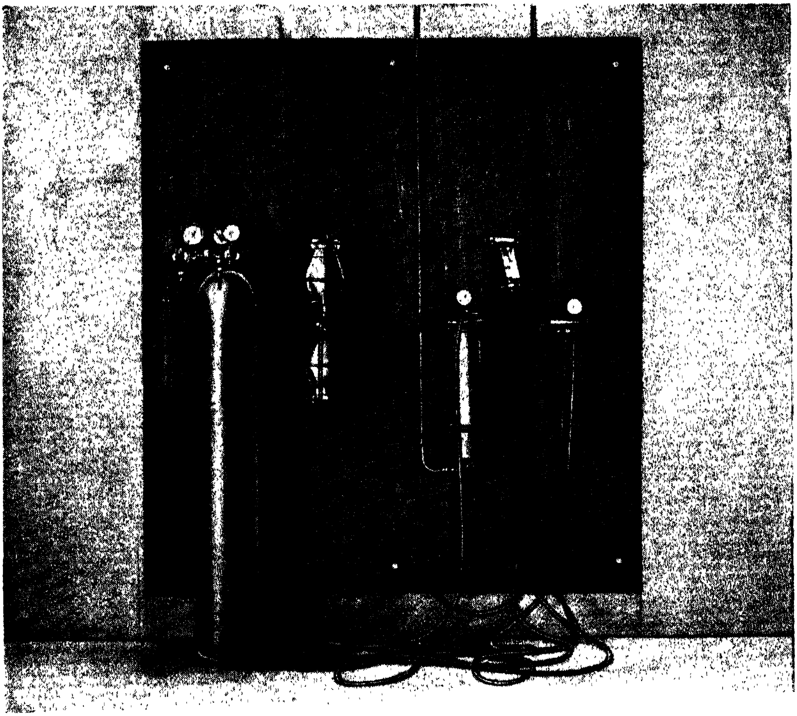

Fig. 76.—Complete Schori Powder Process Installation.

The success of powder pistols is largely associated with the method of supplying the powder from the container. Early designs used compressed air to force the powder along the pipe line, but this frequently causes stoppages due to the compacting of the powder in the pipe. The method used in the Schori pistol is to suck air through the pipe line to carry the powder as a suspension in air. The construction of the container is shown in figs. 76 and 77; it works like an egg-timer. A small eccentric air turbine creates vibration in the container and tends to reduce "packing" of the powder, which is aspirated from the centre. After a time the container is turned upside down.

The container used in the French powder pistol is shown in fig. 77, W. The feeder is inserted into a receptacle holding the powder and the air, regulated by a valve, causes a four-bladed propeller to rotate, thus giving a uniform supply of powder.

Two difficulties are met with in the design of equipment for spraying metal powders. The first is the need for using a large diameter orifice in the nozzle to prevent the clogging of the powder, with the result that a large flame is required, and the second is the maintenance of a regular and uninterrupted supply of powder to the pistol. The size of the powder and the moisture content greatly affect uniformity of supply. The nozzles can be varied according to the size of powder used.

Uses.—Owing to its low costs, the powder process will undoubtedly prove successful in spraying large surfaces with zinc, especially when the coating is subsequently painted or when a mixture of powdered glass and zinc is sprayed. The latter produces an almost enamel-like mass and may prove useful on ships' plates. The powder pistol offers possibilities of spraying powdered bitumen without the use of a vehicle, also brittle metals and alloys of high melting-point which could not be drawn into wire.

Operation of the Schori Pistol.—Sift the metallic powder in a sieve of 100 mesh before placing it in the powder container. The compressed air ought to be as dry as possible, this result being obtained by placing a coke filter in the air conduit. The air should also be regulated, 42 lbs. per sq. in. After having connected the pistol to the compressed air, oxygen and acetylene supplies and the powder reservoir, open the compressed air tap, the tap fitted on the pistol being closed; turn on next the acetylene, the pressure of which should be regulated to between 7 and 10 lbs. per sq. in., light and turn on immediately the oxygen to 35·5 lbs. per sq. in. The flame should now form a tongue 2¾ inches long. Then open tap V (fig. 75). It is necessary to close inlet F with the thumb to induce the metallic powder into the flame, holding the pistol at about 8 inches from the surface to be treated. This distance can be greater according to the nature of the metallic powder and the strength of the flame.

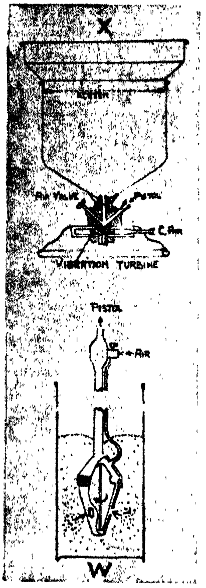

FIG. 77.—Powder Containers.

X Schori type.
W French type.

If the metallic powder is very fine and the flame very strong the powder is burnt and gives off a smoke ; it is then necessary to reduce the flame.

To stop the apparatus, first turn off the acetylene, then when the flame goes out shut off the oxygen and finally the air tap.

Points to be Noted.—The powder container is provided with a small air fan. The powder, according to its nature, flows from one receptacle to another as in an hour glass, but for this it must be very dry.

If the powder is damp, which is very often the case, it is necessary to turn the fan, the wheel of which is unbalanced so as to produce a vibration which will cause the powder to flow. This vibration can be controlled by the admission of more or less air, whichever is necessary.

The compressed air in the standard apparatus serves as the suction for the powder, and assures at the same time the burning of the flame and the cooling of the burner of the pistol.

It is necessary to reduce to a minimum the time for lighting and regulating the flame under risk of melting the end of the centre tube, the circumference of which is grooved.

Comparative details of three pistols are given in the following table :—

TABLE I.—*Comparative Details of Three Types of Pistols* (*Makers' Figures*).

	British Wire	Molten Metal	Powder
Valves	Single-plug type inside casing	Only taps on the Bunsen burner	Finger control for powder ; separate valves for the gases
Moving parts	Turbine and gears encased	None	None
Weight	3½ lb.	6½ lb.	2¾ lb.
Metal form	1, 1½, 2 mm. diameter wires	Ingots melted in furnace	Powder : zinc, 100 ; copper and aluminium, 150 ; nickel, 200 mesh per in.
Limiting melting point	1550° C.	600° C. (aluminium—silicon alloy)	1550° C. (copper highest in England)
Speed of application for zinc	5 lb./hr. ; 17 ft.^{2}/hr. (0.005 in.) 11.9 lb./hr. using 2 mm. wire	16 lb./hr. including stopping	20 lb./hr.
Wastage	10-20%	10-20%	20-30%
Oxygen	30-40 ft.^{3}/hr. ; 25 lb./in.^{2}	None used	50 ft.^{3}/hr. ; 14-28 lb./in.^{2}
Combustible gases	Coal-gas, 45 ft.^{3}/hr. ; 28 lb./in.^{2} ; or acetylene 24 ft.^{3}/hr. ; 10 lb./in.^{2}	Coal-gas, 40-75 ft.^{3}/hr. at town main pressure ; gas for furnace 150 ft.^{3}/hr. for 3 pistols	Enriched coal-gas (ferrolene) 7 lb./in.^{2} ; acetylene 43 ft.^{3}/hr. ; 3 lb./in.^{2}
Air	15 ft.^{3}/minute ; 45 lb./in.^{2}	15 ft.^{3}/minute ; 65-75 lb./in.^{2}	15 ft.^{3}/minute ; 43 lb./in.^{2}
Normal working distance	3 in.	5 in.	10-12 in.
Internal work	1-3 in. diam.-use Rotary nozzle 3-12 in. diam.-use extension and deflector nozzles	Shallow work only	Shallow work
Overhead work	No difficulty	Impossible	No difficulty

CHAPTER IV.

SAND BLASTING AND EFFICIENCY OF SPRAYING.

Preparation of the Surface.

We turn now to consider another factor in successful metal spraying; the preparation of the surface before spraying is commenced. The degree of adhesion of sprayed metallic layers or coatings is much influenced by the form of the surface to be coated; under otherwise similar conditions the adhesion is proportional to the extent of the contact surface. In other words, the coating metal holds the more firmly the greater the contact surface between coating metal and foundation material, and hence the rougher and more complex the surface of the substratum may be. This is easily explained by the fact that with rough surfaces, undercut places exist which makes separation, or peeling, of the coating difficult. Hence in practice it is advisable to roughen smooth objects before spraying. The roughening of glass may be accomplished by means of hydrofluoric acid gas, and of metals by sand blasting. By roughening the surface the cleanliness which is so important is achieved. It is especially necessary with metallic foundations, and a factor of great influence upon the adhesion.

The surface to be metallised should be of an open texture, and thoroughly clean, that is, free from moisture, oil, and scale. With metallic articles this condition is obtained by sandblasting, which should be carried out immediately before spraying, so that there is a minimum risk of troubles due to moisture or grease. To get a sufficiently open grain it is necessary to use considerable pressure and a hard abrasive. The degree of roughness should be of the same order as the size of the sprayed particles.

Abrasive Blasting.—Three systems are in common use :—

(1) *Pressure System,* where compressed air is used to force the abrasive from a closed container along a pipe line for final discharge through a nozzle on to the work.

(2) *Suction System,* in which the abrasive is aspirated to a recompression nozzle from which it is ejected by compressed air.

(3) *Mechanical System,* where the abrasive is fed on to impellers rotating at high speed and is discharged on to the work by the centrifugal forces.

Of these three systems, the first is by far the most important, and is applicable to all types of plant. The second is much less efficient than the first, but has the advantage of simplicity for a limited range of work, such as in cabinets where light abrasive action is required on small articles, handled by the operator. The third system is still in the process of development, but should be very useful for the smaller classes of work, especially those done in barrels, since no compressed air supply is required and the power consumption is very small. A typical example is the " Wheelabrator " machine, shown in fig. 78.

The main element consists of two steel plates bolted together, between which are eight renewable blades of specially hardened metal held in place by suitable countersunk screws. The abrasive is fed through a control cage which allows it to pass from a point in the centre of the wheel tangentially on to the blades, so that the direction of the abrasive can be controlled and discharge not allowed round the whole 360° rotation. The abrasive is fed through the stationary control cage by means of a small impeller wheel rotating with the main wheel and is then thrown through the slot in the control cage. The main wheel, carried on a shaft, is driven by a 15 H.P. motor, through a Tex rope drive, at 2250 r.p.m. At 1800 r.p.m. the cleaning action of the abrasive is only about half that at the higher speed. The surface covered by the blast at 3 feet distance from this type of wheel is about 40 × 3½ inches as compared with about 6 inches diameter for compressed air blasting.

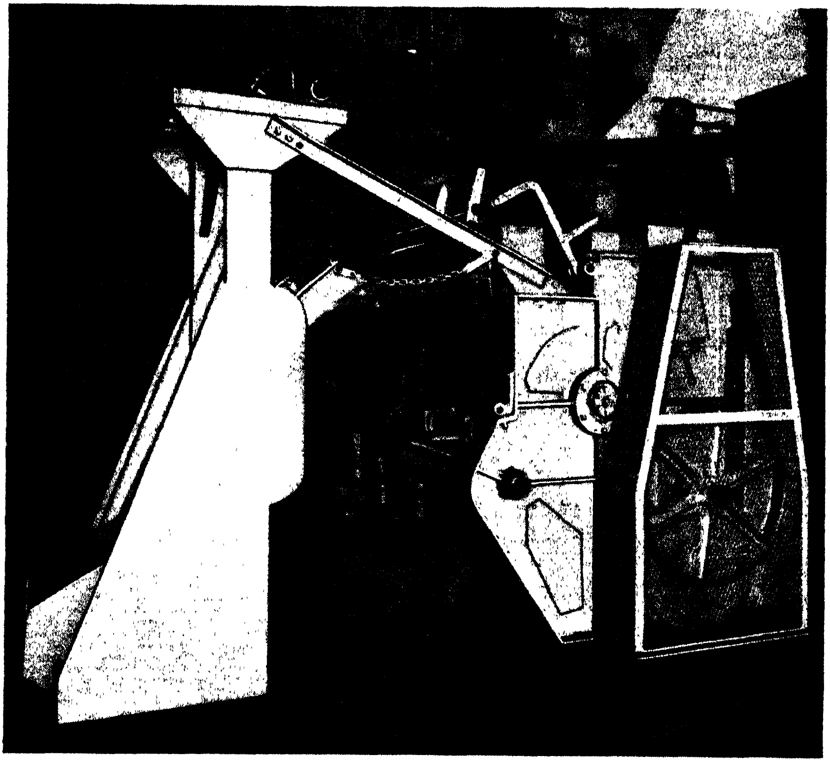

FIG. 78.—Tilghmann " Wheelabrator " Abrasive Machine.

The material to be cleaned can be passed through the stream of grit by means of either a barrel for small castings or a rotary table or conveyor belt for flat articles.

An exhaust system must be provided of sufficient power to remove all dust-laden air from the abrasive cleaning chamber and Home Office Regulations also require the fitting of a dust arrestor to prevent atmospheric contamination.

Well-recognised types of machines are in use for different purposes :—

Chambers or Rooms for large objects, where the operator and work are both within the room and the sand blast is directed on to the work through a nozzle at the end of a flexible hose controlled by the operator. The abrasive after use falls through perforations in the floor and is conveyed to the pressure appliance for re-use (fig. 79).

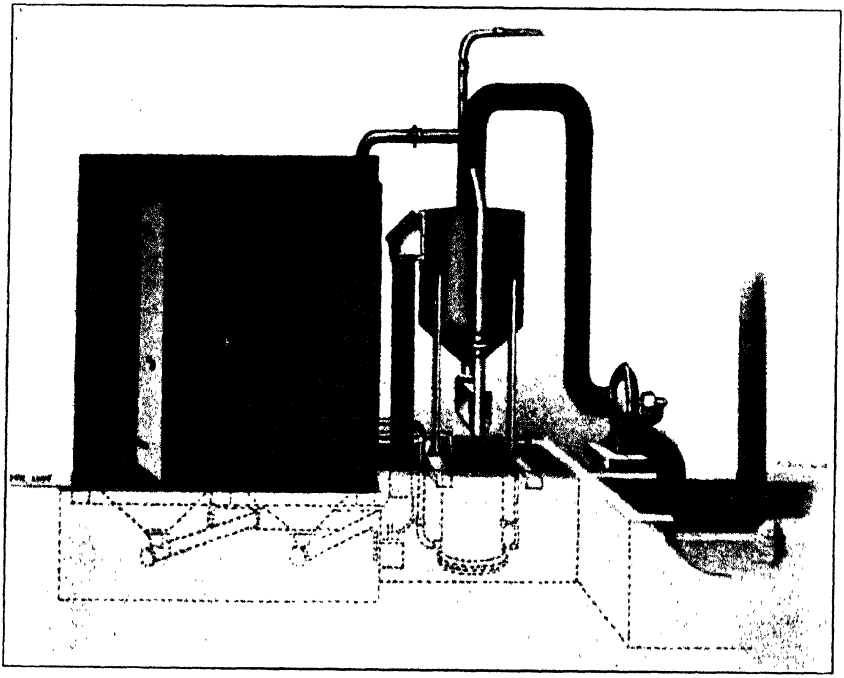

FIG. 79.—Complete Sand Blast Plant.

Cabinets for small general work ; the operator stands outside and moves either a portable nozzle over the work or the work under a fixed nozzle.

Special cabinets are built to suit particular purposes. For instance, a conveyor belt carrying the work may be arranged to travel through the cabinet, while one or more nozzles, mechanically controlled, oscillate so that the jet covers the full width of the belt (fig. 80).

Rotating Barrels, which tumble the articles while the sand blast is projected through one or both ends of the barrel, which is about one-third full. For small articles such as nuts, bolts, pressings, etc., sand blasting followed by spraying can be carried out in the drum shown in fig. 81. The sand blast nozzle and pistol are directed alternately on to the work.

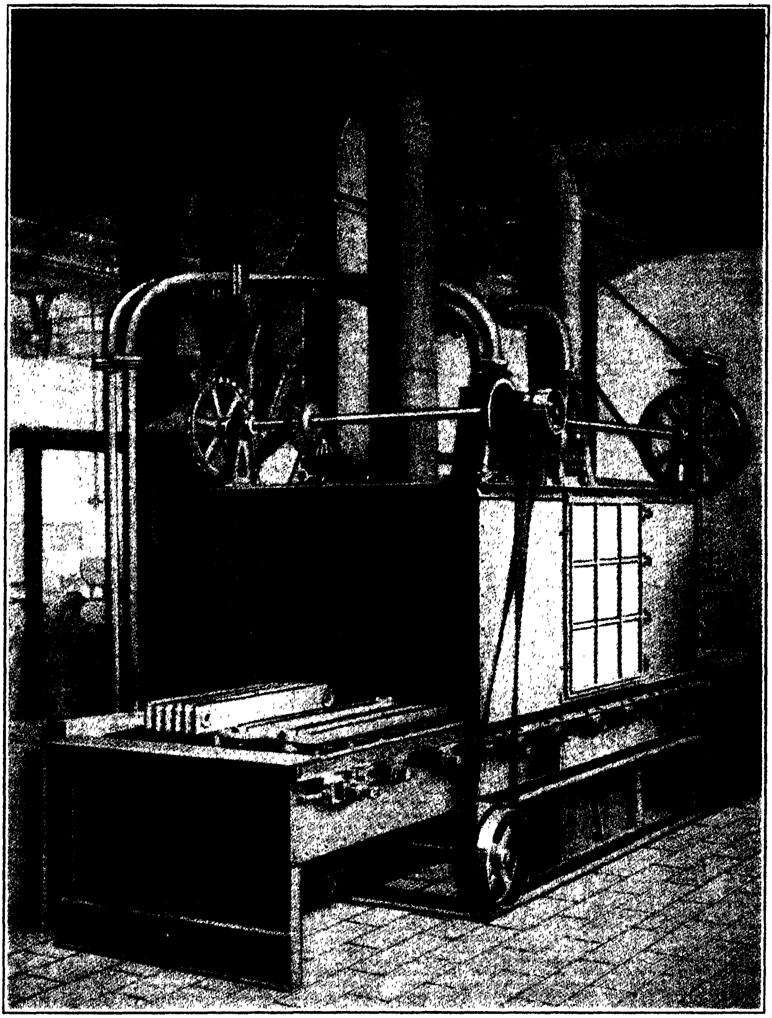

FIG. 80.—Automatic Sand Blast Plant for Large Articles.

Rotary and Reciprocating Table Machines.—In these the table is covered with articles to be cleaned, and moves continuously under the sand stream.

Sand Blast Unit.—Each of the above machines requires a sand blast unit, of which there are two kinds, continuous and intermittent.

Intermittent Type.—This is a unit widely used by metal sprayers and is illustrated in figs. 82 and 83, with the valves in the blasting position. The valve A allows the abrasive to be charged into the pressure tank B. The air supply is controlled through valve C which is interconnected to valve D. During sand blasting A is closed and C and D are open, so that mixed air and abrasive are discharged through the nozzle. The filling valve A (fig. 83) is used to make an air seal when blasting is in process, but when the tank B is being refilled with abrasive, the latter falls over the valve itself. The valve illustrated is so shaped that abrasive can flow freely over it, and it is also provided with a soft rubber disc so that an air seal can be made even though a small piece of abrasive may be trapped between the disc and the seating. If a seal is not made, the consequent rush of dusty air will soon wear a channel in the valve and seating.

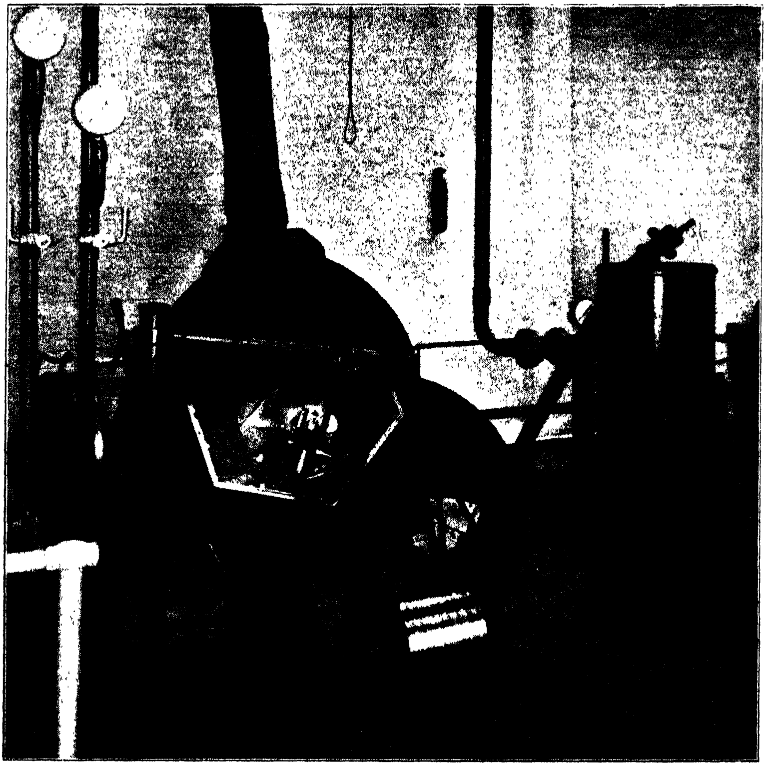

FIG. 81.—Rotary Drum for Sand Blasting and Metal Spraying of Small Articles.

Factors Affecting the Efficiency of Sand Blasting.

Abrasive.—Sand and flint are both very good abrasives, but pulverise rapidly in use and the dust is detrimental to health if breathed. Round iron shot is a very poor abrasive, particularly on steel, but angular steel grit (crushed chilled cast iron) is possibly the best practical abrasive, especially where the workers' health is considered.

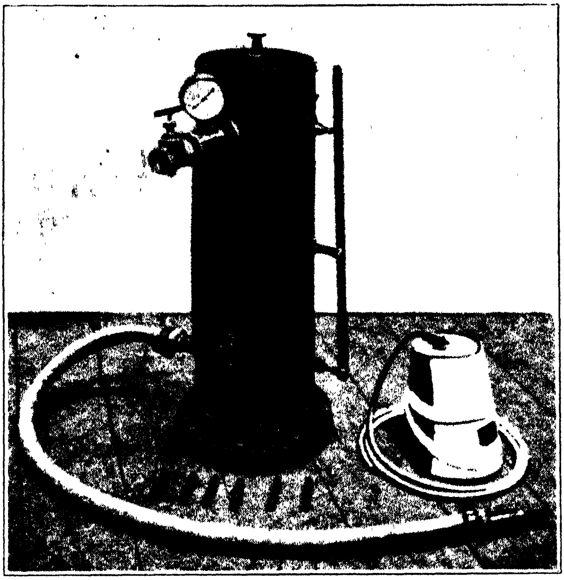

FIG. 82.—Small Sand Blasting Machine.

The effect of the type of abrasive on blasting efficiency, that is the weight of material removed in unit time at constant air pressure and consumption, is shown below (after Neville) :—

Abrasive	Relative Efficiency, Direct Impact, 40 lb./in.^{2}
New steel grit, No. 30	100
Old steel grit, originally No. 30 . .	62
New steel grit, No. 50	92
New flint grit, No. 12	91
Used flint grit, No. 12	90
Mixed new steel grit,—⅓ each of Nos. 12, 24, 30	90

Steel Abrasives on Steel, Air pressure 15 lbs./in.^{2} Nozzle dia. ½ in.	Gms. of Steel Removed per min.
No. 24 Steel shot . .	0·33
No. 12 Steel shot . .	0·35
No. 24 Steel grit . .	1·74
No. 12 Steel grit . .	2·17

Steel grits drop considerably in efficiency with use. Flint grits maintain their efficiency, but pulverise rapidly, due to their crystalline structure, with consequent change in type of surface. According to tests made by Neville, Leighton Buzzard sand loses 10 per cent. of its weight per impact at a pressure of 15 lb./in.^{2}, whereas No. 24 steel grit at the same pressure loses only about 0·1 per cent. Although more expensive in first cost, steel abrasives have from 10 to 20 times the life of sand, whilst their use avoids dust formation. Nevertheless, sand is still preferred for certain classes of sprayed work. The weight of chilled steel abrasives is about 2½ times that of an equal volume of sand, therefore a pressure double that used for sand must be employed in order to obtain equal production. With sand the pressure used is generally from 10 to 30 lb./in.^{2}, whereas steel abrasives are usually worked with 25-60 lbs./in.^{2}, while pressures as high as 90 lb./in.^{2} are not uncommon.

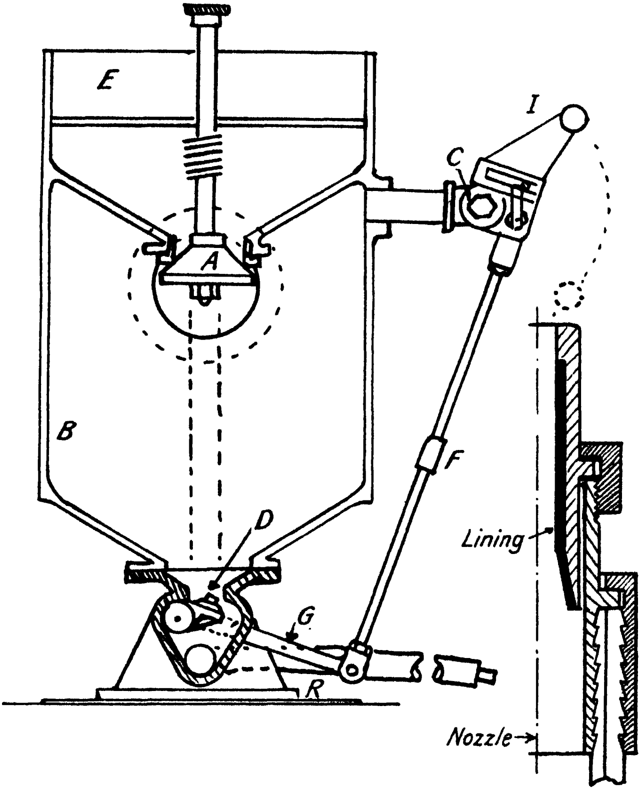

Fig. 83.—Jackman Intermittent Type Sand Blasting Unit, showing Controls and Section of Nozzle (right).

Many grades of steel abrasives are available and it may be stated as a general principle that the grain may be increased in size with the hardness of the material treated and the skin which has to be removed. The larger sizes have a longer life but give a coarse finish. Occasionally it is found that the coarse grit has been crushed from fairly small shot, with the result that a large proportion of rounded surface is present, with consequent low efficiency. As a general guide the following table is suggested.

TABLE II.—*Recommended Abrasives.*

Type of Material	Type of Abrasive	Air Pressure lb./in.^{2}
Non-ferrous castings and soft materials . . .	Fine, angular, *e.g.* No. 60	18-20
Iron castings	No. 24 or 30, angular	25-35
Steel Castings . . .	No. 10 or 12, angular	60-80
Steel stampings, forgings, plates, sections . .	No. 16, 18 or 24, angular	45-60

The analysis of steel shot is carbon 2·9-3·4, silicon 1·3-1·9, manganese 0·4, sulphur 0·1, phosphorus 1·0, chromium 0·1-0·3 per cent., and the diamond hardness is 880.

Abrasive Flow Rate.—Experiments have shown that, for given conditions of air pressure, nozzle size, etc., the amount of material removed from an article for a given power output depends on the quantity of abrasive flowing to the nozzle. This influence is well illustrated in fig. 84. Over a limited range a good efficiency is obtained; larger and smaller flow rates cause a rapid lowering of efficiency.

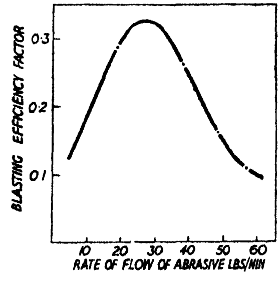

FIG. 84.—Effect of Abrasive Flow Rate on Efficiency.

It is desirable, therefore, for steady working conditions, to open the abrasive regulating valve to a definite amount. One method of doing this, so that opening the air valve automatically gives the correct amount of abrasive flow, is illustrated in fig. 83. The lever G, which opens the abrasive regulating valve, is connected by rod F to lever I on valve C, on which the leverage can be altered such that when the connecting point of I is far from the fulcrum, opening valve C causes a relatively large opening of valve D. In practice, the best position for the point of connection is found by trial and the connection then fixed.

In units with separate control for abrasive and air valves, the latter should be closed after the former, as otherwise the pipe line will tend to become choked.

Air Pressure and Consumption.—Many factors have to be considered when deciding what air pressure shall be used. When capital expenditure must be minimised, a pressure of 15 lbs. per sq. in. may be found sufficient, although a low rate of output will be obtained and the surface may not be rough enough for metal spraying. For steel, a minimum of 30 lbs. per sq. in. is necessary; for woodwork and plaster 10 lbs. would suffice. With otherwise constant conditions, an increase in air pressure produces a higher rate of abrasion (fig. 85) and the nozzle movement may be increased. A comparison of the energy consumption under different conditions of air pressure and nozzle diameter are given in the following table.

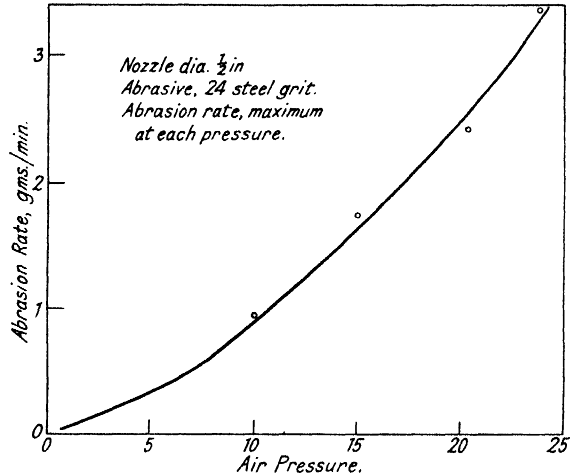

FIG. 85.—Effect of Air Pressure on Abrasive Rate.

TABLE III.—*Energy Consumption in Sand Blasting.*

Working Pressure, lbs./in.^{2}		Diameter of Nozzle, ins.		
		$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
30	Cu. ft. per min. . . H.P. absorbed . .	62 7	90 11	122 14
45	Cu. ft. per min. . . H.P. absorbed . . .	84 12	122 17	165 24
70	Cu. ft. per min. . . H.P. absorbed . .	118 21	170 30	230 40

The relation between power and air pressure is illustrated in fig. 86.

If nozzles are allowed to wear unduly, the air demand at the plant will increase rapidly, or if the air volume is fixed, the pressure will drop and with it the efficiency of blasting. If the pressure is maintained, cleaning should be increased, but it is probably safe to say that, although the air flow may increase twofold, twice as much work will not be obtained from the operator, and wear on the pipe line will be increased. A nozzle should be changed immediately the outlet has worn to such an extent that the time of blasting is out of all proportion to the flow of air and abrasive.

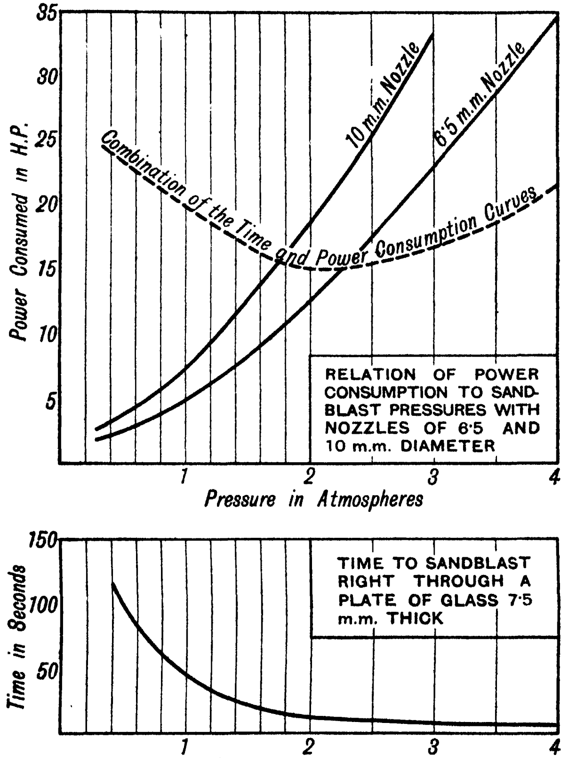

Fig. 86.

Nozzles.—Nozzles are subject to wear at both the inlet and the outlet, each of which has its own peculiar influence. Wear at the outlet is caused by the side thrust of the abrasive against the walls of the nozzle ; the result is a bell-mouthed opening, which causes the abrasive stream to spread.

Nozzles are frequently made from gas tubing, or of white cast iron, and are not expensive in themselves ; but they play an important part in controlling operating costs. To maintain steady conditions, expensive nozzles, lined with hard substances such as boron or tungsten carbide are coming into more general use. Besides regulating working conditions, they generally show a considerable nett saving on nozzle costs, apart from changing time costs. There are now on the market nozzles which are installed under the guarantee that at air pressures not exceeding 90 lb. per sq. in. wear at the outlet end will not be more than 50 per cent. of the original diameter for a period of 1500 hours when using steel grit, 750 hours when using sand and 200 hours when using alumina. The holder is incorporated with and is part of the sand blast hose, and is fitted with a bayonet holder or screw cap. The actual nozzle is turned out of mild steel and lined with boron carbide or similar material. A typical construction is shown on the right-hand side of fig. 83.

Angle of Projection.—The angle of impact of the abrasive on the surface of the article has an important influence on the abrasive rate. A few tests by Neville are recorded in fig. 87. Using No. 24 steel grit on steel plate, 30° was found to be the most efficient angle. On cast iron 50° was found to be best. Using quartz sand the best angle was 15°. In practice, therefore, it is recommended that the nozzle be held obliquely to the work, instead of perpendicularly.

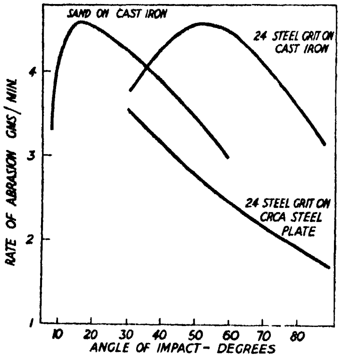

FIG. 87.—Effect of Angle of Impact on Abrasive Rate.

Distance between Nozzle and Article.—The greater the distance between the nozzle and the surface to be blasted, the greater the area covered, but the amount of material removed by abrasion does not increase linearly, due to the fact that the grit loses kinetic energy. As a result, the abrasive rate increases up to some 6 inches distance and then remains practically constant up to 16 inches, as shown in fig. 88.

Length of Nozzle.—The efficiency of a nozzle of ½ inch diameter, measured by loss of weight of articles treated, is only slightly improved by an increase in length above 3 inches.

Effect of Moisture.—A given weight of air at constant temperature can hold less moisture when compressed, but the limiting amount increases with rise in temperature. During compression, air is heated, and its water holding capacity is increased because of the temperature rise but decreased owing to the compression. On reaching the mains the compressed air is cooled, and some water may be deposited, which causes dampening of the abrasive, with consequent clogging. Any nearly horizontal pipes should be arranged to drain back to the receiver. At the compressor end inter- and after-coolers are sometimes used, as are also water separators of either the mat or the centrifugal type.

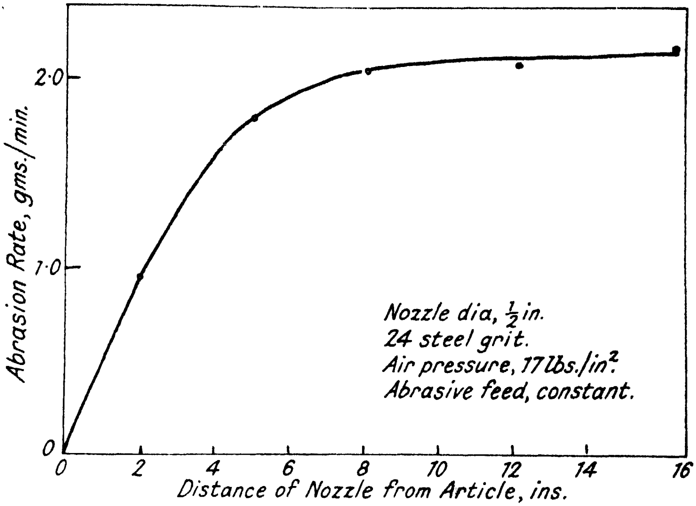

FIG. 88.—Effect of Working Distance on Abrasive Rate.

Dust Extraction.

If the dust generated during sand blasting is to be removed regularly and quickly from the chambers, sufficient air for the purpose must be admitted and correctly distributed, such as by breathers across the roof. The best method of specifying the air volume required is in cubic feet per minute per square foot of floor area, in order to get a certain average vertical velocity of air over the whole floor area. A good average figure is 60 cu. ft. per min.

The pressure at which the fan works will vary as the screens in the dust extraction plant become impregnated with dust. The fan should be of the kind which will maintain a fairly steady air flow even though the resistance may increase slightly.

The removal of the dust from the air can be effected by means of " cyclone " separators depending on a sudden change in direction of the air stream for removing heavy particles. A bag type filter is very efficient for removing the fine dust. The filter may be either the pressure or the suction type, the latter being more expensive, but the fan works with dust-free air. All bag filters require some form of shaking gear for dislodging the dust.

Protection of Operators.—The process of sand blasting by hand, using the ordinary hose apparatus, is unpleasant, and unless proper precautions are taken, may be dangerous to the health of operators. Particles of fine sand and dust entering the lungs may give rise to serious troubles. It is essential, therefore, that the sand blast operative should be provided with adequate protection. A breathing respirator of some such design as illustrated in fig. 89 is of great value in metal spraying, but little good for sand blasting, for which purpose operators prefer to use a combined headgear,

FIG. 89.—Respirator for Use when Metal Spraying.

which is worn to completely cover the head, and includes both goggles and respirator. Various designs are shown in fig. 90, but many other types are in daily use.

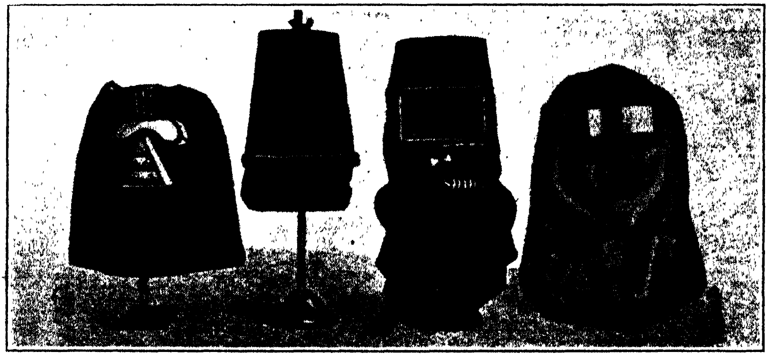

FIG. 90.—Headgear for Sand Blasting Operatives.

When much work is passing through the shops and a man is kept constantly at sand blasting, it is advisable to provide a complete suit for this purpose. In this way the operator is absolutely protected from harm, and his clothes do not become filled with the fine dust which is inevitable in the process; such an equipment is shown in fig. 91.

Some such equipment is also necessary when spraying a poisonous metal like lead, or in fact when spraying at all, especially in confined places. It is at least necessary to wear a muzzle respirator in which the air is filtered through sponges. For work with lead in confined places the operator is protected by a helmet-type respirator fed with warm compressed air, or another more modern type with which it is possible to breathe fresh air without strain through 30 feet of tubing. With lead, tin, and copper, if adequate exhausts are supplied and respirators are used, there is little danger of poisoning, especially if the operator takes small doses of potassium iodide suitably disguised in orange wine, or other medicines and foods as specified by the Board of Trade.

FIG. 91.—Complete Uniform for Sand Blasting Operatives.

When the sand blaster does not stand inside the cabinet, but directs the sand blast hose through a small opening into the chamber from which the dust and sand is continually exhausted by fans, it is then unnecessary to take such elaborate precautions against the inhalation of dust or danger to the eyes.

The Effect of Metal Spraying on the Health of the Operator.

New industrial methods expose the modern industrial worker to a variety of "health risks." Most if not all of these risks can be obviated by the use of properly designed apparatus, by a sound technique in the use of that apparatus, by a clear appreciation of the nature of the risks involved and, above all, by the proper education of the worker in the care and use of the protective apparatus suitable for each risk.

In the metal spraying industry it is as important that the health risks which are incidental to the metal-spraying occupation should not be exaggerated as it is that the real risks should not be overlooked. There is reason to believe that when metal spraying is carried out under proper conditions, the workers can enjoy good health. The following brief notes are intended to give an account of the chief health risks which have to be guarded against and of the usual protective measures which are advised by industrial hygienists.

In this country the legal control of health conditions in industry is vested in the Factory Inspectorate of the Home Office. It is wise and necessary, therefore, to consult the Chief Inspector, Factory Department, Whitehall, London, S.W. 1, before installing the elaborate and expensive apparatus required for certain special processes connected with metal spraying. This applies especially, but not exclusively, to (1) sand blasting, and (2) lead spraying. A great deal of trouble and unnecessary expense may be avoided by following this advice.

The Metals.—The metals most commonly used for spraying are zinc, tin, lead, aluminium, cadmium, copper, iron, nickel, brass and bronze. Of these metals only lead stands out as being a well-recognised cause of industrial illness. Whatever may be the general and desirable precautions which ought to be taken with metal-spraying as such, special and particular precautions must be taken whenever lead is to be used in a spraying gun. Cadmium is sufficiently toxic and tin sufficiently unpleasant in its effects to be treated in a similar manner.

Very finely divided particles of metals act as foreign matter to the organs of the body. Although there is some evidence that "zinc metal spray" has a beneficial effect upon some cases of tuberculosis, it may be asserted, as a general principle, that the less metals gain entry into the body the better. Particles of metal which are breathed into the nose or lung have to be removed either by coughing or else by solution in the body fluids, followed by excretion by the kidneys.

The metal spraying shop should be carefully ventilated, and, wherever possible, a well-designed exhaust booth or cupboard should be used. When, as is the case with large articles, booths are impracticable, the worker should be so placed in relation to his work that the general drift of the air-current is away from his face and not towards his face; he should spray in line with the direction of the air-current in the shop. This can be achieved by the proper arrangement of the working places in relation to the general design of the shop.

Metal spraying is still in its industrial infancy, and hitherto no evidence of ill-effect upon the workers has been discovered except in the following cases: (*a*) lead, (*b*) cadmium, (*c*) blasting, (*d*) tin, (*e*) solvents.

(*a*) *Lead.*—At the temperature at which metal spraying with lead is carried out, the oxidation of a certain proportion of the lead, in the air, is bound to occur. If oxides of lead are breathed, and so gain an entry into the lungs, they are absorbed into the body and there exert a seriously poisonous action. The toxic effects of lead on the human body depend both upon the amount of lead absorbed at any one time and also upon the length of time during which absorption occurs. Lead is a cumulative poison. It is " stored " in the bones of the body and only very slowly excreted. It is of the utmost importance, therefore, that even very small quantities of lead should not be absorbed by workers. Metal spraying with lead ought to be carried out in well-exhausted spraying booths or plants, and the workers using lead should be provided with a protective apparatus, similar to that described elsewhere in this book for the protection of the sand blaster. Any defects which may develop in the apparatus may cause rapid and serious ill-effects upon the worker's health. These effects may be permanent. For this reason frequent and responsible inspection of the whole apparatus is very important.

The earliest sign of lead absorption is slight pallor of the skin—this is the first outward sign of a developing lead anæmia. The complexion loses its ruddy and healthy appearance, and slight and increasing " shortness of breath on exertion " is complained of by the worker. Industrial hygienists have shown that a regular blood-examination, carried out by a trained doctor, at intervals of 2-3 weeks, is the surest way to prevent the slow onset of lead poisoning and to protect the workers from harm.

The late symptoms of severe lead poisoning ought seldom, if ever, to occur if the above precautions are observed. These late symptoms are (1) increasing anæmia, (2) constipation, (3) " colic " or pain in the abdomen, and (4) muscular weakness. If any of these signs are observed, the worker should be seen immediately by a doctor.

It is recognised that the regular taking of milk helps to mitigate the ill-effects of lead on the human organism. Each worker who works with lead should be supplied with ½-¾ pint of milk a day. The calcium in the milk tends to " fix " in the substance of the bones any lead which may happen to be absorbed. So long as the lead is in the bones it does little harm. The harm occurs when the lead is present in the circulating blood. Milk shortens the time of the passage of the lead through the blood stream and therefore tends to lessen the risk of poisoning. No eating or smoking ought ever to be permitted at or near this work. Washing facilities should be provided for the worker.

Cadmium and Tin.—Cadmium is extremely irritating to the nose and throat and eyes. Tin spraying rapidly causes vomiting of a severe kind. These metals should always be sprayed under exhaust. It is not known for certain whether cadmium can produce actual poisoning, but it is known that it may produce " metal fume fever " and pneumonia (see below). Careful observation upon the health of all workers engaged in metal spraying is desirable. It is especially important that the possible toxic effects of new alloys or new methods of working should be carefully examined *before* extensive use is made of them on a commercial scale.

" Metal fume fever " is a well-known, more or less transient, illness from which zinc and bronze workers frequently suffer. It is now recognised that other metals besides zinc and bronze are capable of causing this affection, for " metal fume fevers " have occurred amongst workers with cadmium and magnesium. The illness is notable (*a*) for its acute onset, (*b*) for its usually transient nature, and (*c*) for the fact that it is a condition against which " acclimatisation " can be acquired.

" Metal fume fever " is observed amongst workers who are unaccustomed to their work and amongst those who have been away from work for a period. It resembles influenza. The patient complains of feeling chilly, runs a high temperature, which usually lasts for about three days before subsiding. In general, " fume fever " is not a condition which is dangerous to health, although very severe cases resembling pneumonia may occasionally occur, especially after exposure to cadmium. It is a disorder which is seldom met with amongst metal sprayers. It can be prevented by improvement in the ventilation of the shops or by the provision of exhaust.

Sand Blasting.—By far the most serious risk to which metal sprayers are exposed is the risk of silicosis. This risk is confined to the sand blaster or to other workers who work near to an inefficient sand blasting plant. It has been shown that, in proportion to the numbers actually employed, sand blasters are more likely to suffer from silicosis than any other group of workers. Silicosis is a degenerative disease of the substance of the lung in which extensive scarring (fibrosis) occurs. Its presence can be recognised at an early stage by X-ray examination. It usually takes 7-10 years to develop, and is therefore a very insidious disease. Its later stages are frequently complicated by the onset of tuberculosis, the way for which is prepared by the devitalisation of the lung tissue by the silica. Essentially silicosis is caused by the inhalation of silica (SiO_2) in a minutely divided state. Silica dust which can be seen with the naked eye is less dangerous than the impalpable particles of silica which cannot be seen.

The main points to which careful and unremitting attention must be given, if silicosis amongst sand blasters is to be avoided, are (1) the substitution of automatic blasting for hand blasting wherever possible ; (2) the provision of the most efficient and up-to-date sand blasting plants and protective apparatus—this is not the place to describe plants or appliances, but it must be emphasised that too great care cannot be made in the selection of them ; (3) the frequent detailed and routine examination and repair of all sand blasting apparatus and protective equipment by a competent and responsible person ; (4) care in the choice of personnel. The sand blaster should be a responsible, intelligent individual who understands the principles upon which his apparatus and appliances work and is free from tubercular taint.

In many industries, steel shot can be substituted for sand in the blasting process. Shot blasting is, unfortunately, impracticable in the preparation of thin sheets for metal spraying. It is greatly to be wished, however, that a suitable and efficient substitute for sand should be found for this work.

These then are the most obvious and serious health risks to which metal-spray workers are exposed. In brief it is hygienically desirable that all reasonable steps should be taken to lessen the amount of metals in the air which the workers breathe ; it is essential to do lead spraying only under strictly-guarded conditions ; it will be wise to keep a very close watch upon the health effects of new metals and methods, and it is important to treat sand blasting as a potentially dangerous occupation.

Solvents are being increasingly used for cleaning metal parts, especially aluminium. Carbon tetrachloride and trichlorethylene are the solvents most commonly used for this purpose. Both are poisonous and should be used in a suitable exhaust cabinet. Acute poisoning from the fumes of any of the chlorinated hydrocarbons results in giddiness, unconsciousness and it may be death. If any worker faints or feels giddy whilst using either of these solvents he should be taken into the open-air, his clothes should be opened and a careful watch kept upon his breathing. In very extreme cases artificial respiration might be necessary.

Chronic poisoning shows itself as headache, debility and especially loss of appetite and even vomiting. Sickness is commoner when carbon tetrachloride is the solvent used. It is generally agreed that carbon tetrachloride is more toxic than trichlorethylene. A number of cases of severe and dangerous liver disease have followed the use of carbon tetrachloride.

If efficient exhaust apparatus is used, no ill-effects whatever should be experienced from the solvents. Carelessly used they are definitely dangerous. Trichlorethylene should be preferred wherever possible.

Spraying Tables and Hoods.

The maximum loss occurs with tin and lead, and may amount in exceptional cases to as much as 40 per cent. With copper and zinc the loss is only 20 per cent., and with aluminium 8 per cent. When working on the bench this powder is collected in the exhausts and is a by-product, but the presence of the fine metallic powder is a menace to the operator's health; it is therefore, as already mentioned, necessary that he should use some type of respirator. From two points of view, therefore, it is desirable to employ some method of withdrawing the metal dust and vapour not deposited upon the objects being sprayed from the room in which the operation takes place. Various devices have been constructed and recommended for this dual purpose, and it depends upon the nature and size of the articles to be sprayed as to which type of dust-exhausting plant should be used.

Perhaps the simplest design of spraying table is merely an ordinary iron table provided with an exhausting cover at the back, connecting with the large iron exhausting pipe in which a partial vacuum is created by a revolving fan at one end. This table is suitable for almost all ordinary work of very variable size.

For some kinds of work it may be sufficient merely to employ an exhausting hood.

Final Treatment of Sprayed Coatings.

Turner and Ballard in their paper before the Institute of Metals in 1924 indicated that the surface of sprayed metal is always matte unless it be subsequently polished. It would be well, therefore, to point out that the chief objection to the use of sprayed metals has been that they have been found to be porous. By careful manipulation of air pressures it is quite possible to spray coatings of tin, lead, and zinc that will be almost non-porous to liquids. It has, however, been found impossible to make coatings of copper, brass, and the higher melting-point metals non-porous by means of the pistol alone. The speed of spraying and the distance of the pistol from the work influence the nature of the coating produced. It has been found possible to metal-spray a piece of metallic sodium with so non-porous a coating of lead and tin that no action occurred when the sprayed sodium was thrown into water.

There are, however, methods which may be and are employed in commerce to-day for making sprayed coatings non-porous—*viz.* mechanical, thermal, and chemical.

Mechanical work (such as hammering, wire-brushing, or blasting with ball shot) does not give perfect satisfaction and is cumbersome. This method is not used where other methods are applicable.

Very good results have been obtained by precipitating within the pores of the metal an insoluble, non-poisonous chemical compound.

Similarly, one may bring about the formation of an insoluble chemical compound in the pores of the sprayed metal by means of a polymeric change in certain mixtures of organic chemicals.

All coatings may be made to take a high polish by the usual methods of buffing. It is necessary to make the coating at least 0·015 inch thick for polishing.

In most cases the coating applied for decoration requires subsequent treatment, usually of a very simple nature. In order to give a shine instead of the matte appearance, brushing with a fine wire brush generally suffices. The brushes should have nearly the same colour as the metal to be brushed, or discoloration results; thus for tin, zinc, and aluminium coats, brass wire brushes must not be used, but nickel silver, iron, or steel ones. Articles which are to receive a high polish must be given an initially thick coat; the places to be polished are first rubbed with emery paper, or filed or polished with an emery buff, smoothed, and then polished with cotton bobs and such polishing materials as rouge, tripoli, chalk, and stearine oil. Another method of improving the appearance and rendering the coatings more solid is that of smoothing them by hammering, a process only really suitable for lead, copper, and aluminium. The hammering must be gentle so as not to stretch and loosen the coating. For artistic articles, chasing and "patinising" may be carried out, but little need be said of these operations since they are arts requiring special knowledge and practice. The formation of a "patina" on thinly coated porous materials, articles of plaster of Paris, terra cotta, etc., only gives good results, we are informed, with acids and similar liquids, if the articles are first soaked in paraffin wax so that the "patina" liquid cannot soak into the foundation material. If this is not done the acids escape again from the inside and cause objectionable marks and sometimes even damage. It is, therefore, well to obtain the patina by dry means; by gases or vapours such as H_2S, a process which is now becoming more common. To protect the patina it is usual to cover it with a colourless lacquer of the well-known "celluloid" or "Japan" types, which give coatings which detract but little from the metallic effect.

Efficiency of the Process.

It has now been shown that the metal spraying process, developed through the inventive and experimental work of Schoop, Herkenrath, Matzinger, Meurer, Hopfelt, Jung, Schori and others, has become a practical means of metallisation. To be used for coating articles of commerce, however, it had either to prove more easy to use, more economical in use, or to produce more lasting or beautiful results than did other processes. The inventor of the wire process once said that the invention of the process had been easy—a fight with the material; the commercial development had, on the other hand, been real hard work in competition with other men and their processes.

One does well, therefore, to try and consider now how efficient the process is. Firstly, it should be clearly understood that the cost of any metal-spraying work is dependent on wages; patent rights, plant upkeep, gases, and metal do not, taken all together, equal the wage bill for the operators. Any considerable reduction in the present cost per square foot sprayed must, therefore, be contingent mainly upon the production of spraying apparatus which permits of more rapid operation by the men actually working the process. For routine work, mass-production methods may be introduced, such methods have been tried with great success on certain types of work in all the more important countries of Europe. Many articles cannot be so treated, and one naturally asks what it will cost to spray such-and-such in which one is particularly interested. Any costs given here will be of only indirect value, for the processes are rapidly expanding, and with extended operation one may reasonably hope for better and better methods of working and more and more competitive prices.

Arnold has stated that the initial drawback as regards comparative costs is the use of wire. It is true that wire or powder is an expensive form of metal to use as the raw material of the process, but it has been used with success under present conditions. However, one may reasonably question Arnold's statement, and the authors have found that the cost of the wire or powder sprayed is but a small proportion of the overall costs in most cases.

The losses during spraying are considerable, regarded from the efficiency balance-sheet point of view. Of the energy produced by the gas combustion for the melting flame only one-fortieth is actually used in melting the wire. In other words, considered as a melting furnace the pistol is very inefficient. The rest of the heat is carried away by the expanding air stream.

Naturally the speed of working the pistol depends partly upon the melting-point of the metal in question, but it is possible to vary this speed within certain limits. There is, however, in all probability a definite speed at which the best results will be obtained with any metal, for by obtaining the correct speed for lead, tin and zinc it has been found possible to spray coatings of these metals that are practically non-porous to liquids.

TABLE IV.—*Pressures and Consumption of Gases and Metals using Compressed Coal-gas (Calorific value* 450 *B.T.U.) and Oxygen—English Wire Pistol.*

Wire						Gases		
						Coal Gas	Oxygen	
Metal	Dia. mm.	Speed, ft. per. min.	Metal sprayed, lbs. per hour	Weight of 1/1,000 in. Metal per sq. ft., ozs.	Area in sq. ft. covered per hour, 5/1,000 in. thick	Pressure, lbs. per sq. in.	Pressure, lbs. per sq. in.	Cu. ft. per hour
Tin	1·5	20	10·2	0·601	39	24	23	37
Lead	1·5	25	19·6	0·938	45	24	23	37
Zinc	1·5	12·5	6·3	0·663	23	27·5	25	41
Zinc	1·0	21	4·8	0·663	17·5	27·5	25	41
Cadmium ...	1·0	25	6·9	0·730	21	27·5	25	41
Aluminium ...	1·0	13	1·2	0·211	17·5	27·5	26	43
Copper	1·0	8	2·3	0·732	8·4	27·5	26	43
Brass	1·0	9·0	2·5	0·710	9·5	27·5	26	43
Nickel	1·0	5·0	1·4	0·730	5·5	27·5	27	45
Iron	1·0	5·5	1·3	0·640	6·6	27·5	27	45

TABLE V.—*Average Figures for English Wire Pistol, using Dissolved Acetylene.*

Metal	Acetylene lbs./sq. in.	Oxygen lbs./sq. in.	Speed ft. per min.
Lead	13	14	24
Tin	13	14	21
Zinc	16	17	24
Aluminium	16	17	12
Brass	22	23	11
Copper	23	24	10
Nickel	24	25	5·5
Iron	25	26	6·5

The approximate consumption of wire and gases is given in Table IV using coal-gas, and in Table V, using acetylene. Table VI is for a higher speed nozzle.

TABLE VI.—*Consumption Figures using* 2 *mm. Nozzle. Air Pressure* 50 *lbs./sq. inch.*

Metal	Oxy-Coal Gas			Oxy-Hydrogen			Oxy-Acetylene		
	Oxygen Pressure, lbs. per sq. in.	Coal Gas Pressure, lbs. per sq. in.	Wire, lbs. per hour.	Oxygen Pressure, lbs. per sq. in.	Hydrogen Pressure, lbs. per sq. in.	Wire, lbs. per hour.	Oxygen Pressure, lbs. per sq. in.	Acetylene Pressure, lbs. per sq. in	Wire, lbs. per hour.
Tin	24	25	22·6	19	20	28·0	17	16	24·5
Lead	24	25	35·0	19	20	41·5	17	16	40·5
Zinc	27	29	11·9	25	26	12·5	25	24	11·9
Copper ...	28	29	6·0	26	27	7·0	26	25	6·0
Aluminium ...	28	29	2·4	27	27	2·9	26	26	2·5
Iron	31	32	3·0	30	30	3·5	27	26	3·5

These tables are from information supplied by Metallisation, Ltd., Dudley, in 1938.

Turner and Ballard summarised the data at their disposal in the following manner:—

" The wire consumption per hour is given in Tables IV to VI. Table VII shows the consumption of oxygen. When using coal-gas with oxygen it is found that the amount of coal-gas used is 1·5 times that of oxygen (*i.e.* when the calorific power of the gas is about 450 B.T.U. per cubic foot). The amount of hydrogen actually used is 2·8 times that of the oxygen, or more than that required theoretically. When using acetylene, the oxygen figures multiplied by 0·75 give the consumption of the acetylene."

TABLE VII.—*Oxygen Consumption, with Hydrogen as the Combustible Gas (in cu. ft per lb. of metal sprayed).*

	1924	1936	1938
Lead	2·64	1·03	0·61
Tin	2·86	0·96	1·06
Zinc	5·32	4·55	3·79
Copper	10·82	9·6	10·0
Nickel	14·6	17·8	15·9
Iron	17·4	21·2	18·0
Aluminium . . .	22·7	21·6	20·0

The approximate consumption of oxygen with other gases is given by the formula—

x = consumption of oxygen per lb. with hydrogen
$x \times 1{\cdot}7$ = ,, ,, ,, coal-gas
$x \times 0{\cdot}8$ = ,, ,, ,, acetylene.

Different countries use different pressures of air and gas as well as slightly different types of pistols. One cannot, therefore, safely transfer figures given for foreign practice to home conditions.

TABLE VIII.—*Operating Pressures, Gas Consumption and Speed of Working of Mogul Pistols.*

	Acetylene		Oxygen		Compressed Air		Speed
	Lbs./in.^{2}	Cu. ft./hr.	Lbs./in.^{2}	Cu. ft./hr.	Lbs./in.^{2}	Cu. ft./hr.	Lbs. metal/hr.
1	25	45	27	52	80	45	As below.
2	20	39	22	45	80	45	13 per cent. less than 1.
3	34	15	17	40	80	45	25 per cent. less than 1.

MODEL A.

	Lbs. per hr.
Stainless steel, . . .	**6·1**
Monel metal, . . .	**4·9**
Nickel, ...	**5·2**
Nichrome, . . .	**5·5**
Iron, ...	**5·3**
0·8 per cent. carbon steel, .	**7·1**

MODEL B.

	Lbs. per hr.
Copper, ...	**9·9**
Bronze, ...	**9·5**
Brass, ...	**11·5**
Aluminium, . . .	**5·5**
Zinc, ...	**2·5**

Table VIII gives operating data for the American pistol designed mainly for building-up work; three sets of pressures can be used according to the rate of spraying required.

It should be clearly understood that the costing of metal-spraying work tends to be based upon the *area covered.* With certain other processes, however, such as galvanising, the cost is generally based upon the *weight treated.* Thus assuming for the moment that an article could be coated by either process with equally good results, the metal spraying would be preferred if the article had a considerable mass in proportion to its surface, *e.g.* a heavy casting, whereas galvanising would be cheaper under the reverse conditions where the surface area was great in comparison to the mass, *e.g.* in the case of a thin sheet or plate less than 3 or 4 mm. thick. Hence it is probable that spray zincing will never be able to replace galvanising in the sheet-metal industry, but it will soon have replaced other methods of zincing in the heavy metal industries. With cast-iron parts spray zincing will rapidly become more common.

The location of the spraying operation naturally affects the cost of the operation. Under ideal conditions in a spraying works the stationary compressors, large gas generators, furnaces, fume ducts, etc., all aid economy, and the straying spray of metal is recovered as a valuable by-product, metallic powder. In the open field or ships' holds, on bridges and girder work, the cost must be somewhat higher, but then no other method of metallisation can possibly cope with such work.

Metal Losses.

The causes of metal losses are as follows:—

1. The particles which miss the objective.
2. The particles rebounding from the surface.
3. The volatilisation of the metal in the flame.

The first point is directly dependent on the shape of the object being sprayed and not on the properties and working of the pistol. The spraying of steel window frames would entail a much greater loss than when coating a large gas-holder.

The vaporising of the metal in the flame can be largely prevented by the correct operation of the pistol.

With regard to the second point, the influence of this variable was studied by Thormann, who used a sheet (20 cm. square) large enough to prevent particles from missing the objective. The sheet was weighed before and after spraying a weighed quantity of wire. The results are shown in fig. 92.

There is a slight falling-off in efficiency with an increase in both nozzle distance and air pressure. The former is due to the reduced velocity and temperature, which render the particles more liable to rebound from the object.

The efficiency is increased with an accelerated feed, which may be due to the larger size of the particles, which do not cool so rapidly as the fine particles which are sprayed with a slower feed.

Increased hydrogen pressure results in a loss in efficiency on account of the greater oxide content.

Estimating Costs.

In estimating costs of metal spraying no hard and fast rules can be set down, for each job usually represents a different problem, and the variation in the cost of gases and materials makes it inadvisable to record costs on a square foot basis which would apply to various parts of the country.

Applications may be divided into two classes :—Industrial, such as the coating of tanks ; and decorative, such as architectural work. In coating along edges and grill work there is a considerable metal loss, and when the surface has to be polished the coatings must be thick enough to allow for metal removed in grinding.

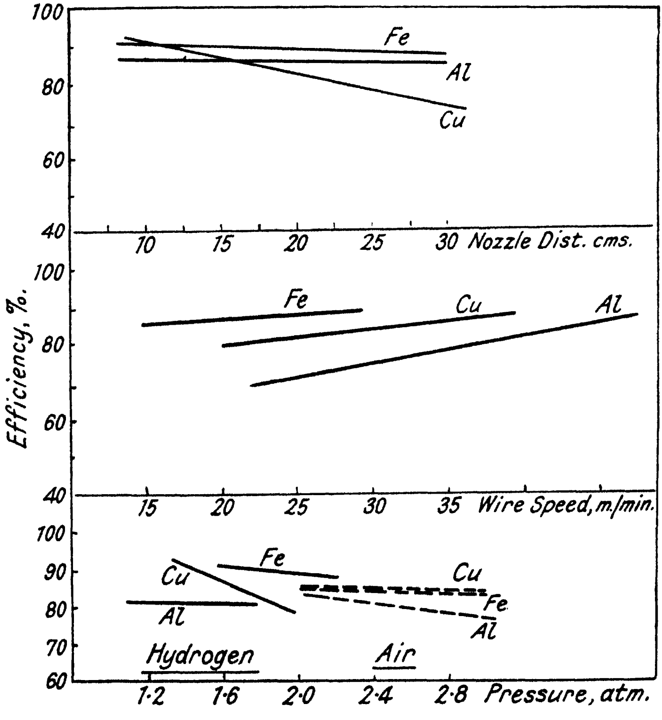

FIG. 92.—Effects of Nozzle Distance, Wire Speed and Gas Pressures on the Loss of Metal during Spraying (Thormann).

According to Boyden (*The Metallizer*, April 1934, p. 17) it has been found that the average man will spray only during 70 per cent. of the time for which he is paid. This apparent waste of time, however, is accounted for in changing tanks, moving work about, greasing equipment and, on particularly tiresome work, some time is spent in resting.

In America, wire pistols are sometimes grouped into standard, high-speed and hard metal units and, from a comparison of costs, the standard unit seems to be the most practical unit for all-round results, although at first glance the high-speed unit might appear more economical from spraying cost (*i.e.* labour and gases). The spraying cost is only a small percentage of the total cost and the main advantage of the high-speed unit lies in its ability to coat nearly twice as fast as the standard unit.

The hard metal unit has an advantage over the standard pistol when spraying hard metal, but is essentially a lathe tool. Typical figures given by Boyden are as follows :--

Cents per 0·001 *inch Coat.*

	Lead	Tin	Cadmium	Steel	Aluminium	Copper
Standard pistol . .	0·022	0·051	0·10	0·05	0·034	0·036
High-speed pistol . .	0·021	0·047	0·10	—	—	—
Hard metal pistol .	—	—	—	0·03	0·022	0·024

CHAPTER V.

NATURE OF SPRAYED METAL.

In discussing the nature of sprayed metallic coatings, difficulty necessarily arises from the fact that their properties are largely interdependent one upon another, so that no very hard and fast line can be drawn between them. Thus we have cohesion and strength dependent upon one another, and to some extent also upon the thickness of metal applied. In the following discussion we use the word cohesion to imply adherence of the individual metal particles to one another, while by adhesion is meant the sticking of the particles to the foundation material.

Permeability and oxide content necessarily influence the density and hardness, the latter also varying with the cohesion. It is thus evident that each of these properties is more or less a function of the other, while also dependent upon :—the metal being sprayed ; the melting gas employed ; the air and gas pressures ; speed of working, and other factors. So that it is impossible to avoid some slight overlapping in the discussion of sprayed metal coatings.

Formation and Structure of Sprayed Coatings.—It would seem reasonable to imagine that the metallic spray issuing from the nozzle of the pistol would be very hot, and that the individual particles would be in the molten condition, and, as a matter of fact, very close to the nozzle this is probably the case. It is, however, a surprising fact that the hand held a few inches from the nozzle of the pistol will receive a metallic coating, yet experience little more than a warm air blast ; there is certainly no evidence of great heat such as would be expected from the deposition of a molten metal spray.

It is logically obvious that at some region quite close to the point of fusion of the metallic wire, the spray must be in the molten condition, but that it is still molten when some 4 or 5 inches distance from the nozzle is not quite so obvious.

The problem is rendered still more obscure by the fact that a thermometer held in the spray at this distance registers about 70° C. when spraying iron. Now the melting-point of iron is about 1500° C., and the metal must have attained this temperature before it could be pulverised by the air blast, so there is evidently a very rapid cooling or else the thermometer does not record the true temperature of the metallic particles.

These questions have a definite bearing upon the explanation of the manner of formation of sprayed metal coatings, because it would seem unlikely that cold, solid, metallic particles driven however forcibly against a moderately smooth surface would either cohere or adhere to any considerable extent, yet in practice such is found to be the case. Various theories have been put forward to account for this adhesion and cohesion of the sprayed particles. It is readily conceivable that a spray of perfume or paint would adhere to a surface, since it is a matter of common everyday observation that liquids will behave in this way. But as there is some uncertainty about the state of the sprayed metal particles, whether they be molten, plastic, or solid at the moment of impact, the question is less easily answered in the case of this process.

The fact that fine fabrics, combustible materials, and even certain explosives may be metallised without danger from the heat of the particles has been explained by Günther and Schoop as due to the suddenly expanding compressed air very much lowering the temperature of the minute particles issuing from the barrel, and to the protection afforded to the substance below by the first thin film of metal deposited. And to explain the formation of coherent and adherent coatings from such cool metal spray, they suggest that in great part the energy of movement of the metallic particles, which is given to them by the transporting blast, is converted on striking the surface into heat, so that although the particles exist in the solid state during transport they become on impact plastic for an instant, and during this transient heated period they weld together into a firmly adhering and coherent layer.

This opinion concerning the formation of sprayed layers has been combated by several authorities, notably in the proceedings against Ger. Pat. 258,505 on 27th April 1909. The above authors attempted, however, to substantiate their belief by citing the somewhat analogous case of the development of heat in a lead bullet on impact with a solid target. The bullet, as is well known, is flattened and simultaneously heated, and it is claimed that if this deformation and heating occur with large bullets it probably occurs also when the minute particles of metallic spray impact upon the surface to be coated. Thus they claimed that a typical welding, characterised by the simultaneous application of heat and pressure would be the result.

In short, then, the theory assumes that the particles solidify at some region between the point of fusion and the object to be metallised, and that the pressure of impact generates sufficient heat to cause either their re-liquefaction or at least their momentary conversion to the plastic state, resulting in a close union or even welding of the particles to one another and to the foundation material. The assumption that there is any welding of the particles sprayed on to a cold surface has been stated by Arnold* to be incorrect; this writer asserting that such welding or fusion only occurs in the case of metals of low melting-point, and provided that the total heat accumulated during the formation of thick coatings of such metals is sufficient to produce this result. Arnold points out that in ordinary thin coatings such fusion can never be observed, but that, on the contrary, photomicrographs invariably show lines of demarcation between adjacent particles.

All that the microscopical examination reveals is the certainty that the particles are in a soft condition when they reach the substratum, or are re-softened by the impact. Arnold further claims that a simple calculation

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* Arnold, H.: *Zeit. für angewandte Chemie*, 1917, **30**, (1), 209, 218; and *Met. Ind.*, 1918, **12**, 121, 146, 165.

shows that the velocity of the metallic particles is insufficient to weld or fuse them together. If t represents the melting temperature of the metal, c its specific heat, s the heat of fusion, v the velocity of the metal previous to impact, and p the weight of one of the particles, then the calorific energy necessary at the moment of impact to fuse the metal particles will be:

$$\frac{pv^2}{2g \cdot 427} = p[c(t-70) + s]$$

This assumes that, as is said to be the case with aluminium, for example, the temperature of the particles at the moment of impact is 70° C. It follows therefore that

$$v = 91\sqrt{c(t-70) + s}$$

By substituting actual values in this formula, the velocity necessary for fusing the various metals is found to be as under:

Lead	Tin	Zinc	Aluminium	Copper
337	446	763	1274	1046

metres per second.

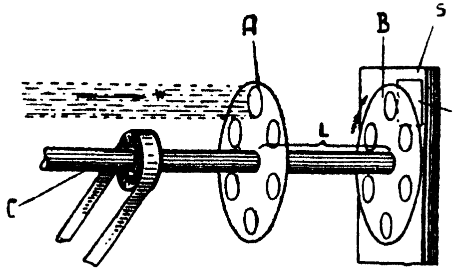

FIG. 93.—Apparatus to Determine Velocity of Metal-spray Particles.

These figures would amply prove the impossibility of melting by impact were the argument irrefutable, particularly when it is borne in mind that the effluent velocity of the projected gas from a simple nozzle is very little greater than the velocity of sound. Arnold has also endeavoured to ascertain the velocity of the particles by experiment, taking into consideration the fact that, in order to obtain results that are applicable in practice, it is necessary to measure the velocity at the same distance as that at which the article to be metallised is situated from the nozzle of the apparatus. At different distances from the nozzle it is evident that the velocities will vary considerably in consequence of the frictional resistance of the air; and another point to be remembered is that the great divergence in the size of the individual particles also greatly affects their relative velocity. Nevertheless, the experiments have afforded interesting information, at least with regard to the order of the dimensions. The apparatus employed is illustrated diagrammatically in fig. 93. Two discs of metal, or preferably glass, A and B, of equal size, are mounted on a common axis C at a distance of L apart. Behind the disc B is an independently mounted screen S, provided with a slit into which weighed strips of roughened metal are inserted. The discs have a number of circular perforations arranged at equal distances apart, their centres lying on a circle concentric with the periphery of the disc. The diameter of each of the holes is equal to the distance between the holes themselves. The discs are greased to reduce to a minimum the amount of metal adhering to them in spraying, and to prevent any wearing of the edges of the holes. In carrying out the velocity determinations the discs are rotated at a speed represented by u. If, at a time ($t = 0$) the metal spray passes through the uppermost hole in the disc A, then it requires a time L/W to reach the disc B. During this time, however, the discs have revolved and consequently the metal spray does not, as a whole, pass through the hole in disc B, but, in part, impinges on the space between two of the holes. If the speed of the second disc be increased, the amount of metal deposited upon the weighed strip diminishes progressively to a minimum, and then increases again to a maximum.

If T represents the time of a revolution of the disc, p the number of holes, and u the number of revolutions at which the first minimum of deposit is attained, then

$$\frac{T}{2p} = \frac{1}{2pu} = \frac{L}{W}, \text{ or } W = 2puL$$

The practical measurements performed by this method showed that the mean velocity of the particles, at 10 cm. from the nozzle, is very low, being about 120 metres per second in the case of brass, and 140 m. for zinc. This demonstrates that there can be no question of any fusion of the particles by mechanical energy, and that their plasticity is mainly due to the successive heating and the proximity of the flame. Schoop's assumption that the velocity of a sprayed particle is at least equal to that of a rifle bullet is, therefore, according to Arnold, incorrect. The speed with which the whole cycle of operations is completed must be taken into consideration. The solid metal of the wire is melted, projected, and once more solidified and rigid within a fraction of a second. These tests have been repeated and confirmed by Schenk.

A second theory, favoured by Karg, Kutscher and Reininger assumes that cold, solid particles of metal are hammered into the pores of the article by the great force behind them. The particles are considered to be cooled by the cold expanded air, and Karg * has worked out the temperature of the air on a basis of adiabatic expansion, the result being 63° C. for the expanded air, with an initial pressure of 2·2 atmospheres and a temperature of 20° C. He has not borne in mind, however, that the pressure at the beginning of spraying is considerably lower than that in the container owing to the appreciable loss in the throttle of the pistol, and also that the air after its release passes through the melting flame.

Work by Thormann has shown that the temperature of sprayed iron particles at a distance of 5 inches from the nozzle is 1000° C. as measured in darkness by means of an optical pyrometer, and it is well known that if the pistol is directed to one spot at a close distance the deposit can be melted. Thormann has measured the rise in temperature of a sheet during the spraying of steel, copper and aluminium by means of a thermocouple fastened to the back of the sheet and protected against loss of heat by radia-

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* Karg, *Korrosion u. Metallschutz*, 1927, **3**, 110.

tion. The results shown in fig. 94 indicate a very rapid rise in temperature at the commencement of spraying, finally reaching a constant level. Care must be taken, therefore, when building up articles, to prevent distortion.

Turner and Budgen, although unable to support Schoop's theory that welding of the particles does occur, are of the opinion that the particles remain during the whole of this flight in either the molten or, more probably, the plastic condition. They are doubtless carried at approximately the same speed as the pulverising blast, and therefore suffer no appreciable cooling effect from it. Because the blast does not move relative to their surfaces, so long as they are in flight, it cannot remove much of their heat and, moreover, the time does not suffice for it to do so. The particles go with the air and are impacted before they have time to solidify; they are probably plastic at the moment of impact. At the instant of striking, however, the air blast begins to rush past the now stationary particles and thereby chills them. The low temperature registered by a thermometer held in the blast is thus easily explained in a similar manner. The temperature there recorded is of a certain volume of mixed metal spray and air, and is the mean resultant of a relatively very small volume of molten metal and an enormous volume of cool air. So that though minute particles of, for instance, molten iron at more than 1500° C. are impinging upon the thermometer bulb, the immense volume of cool air blowing past the bulb immediately carries off the heat from the fixed particles. If a miniature thermometer could be fixed to one of the minute metallic particles during the time of its passage from the muzzle of the pistol to the target, a temperature approximating to the melting-point of the metal would be doubtless recorded, since there is no appreciable rush of air past the particle to cool it, the latter travelling, as it does, with the air until the moment of impact.

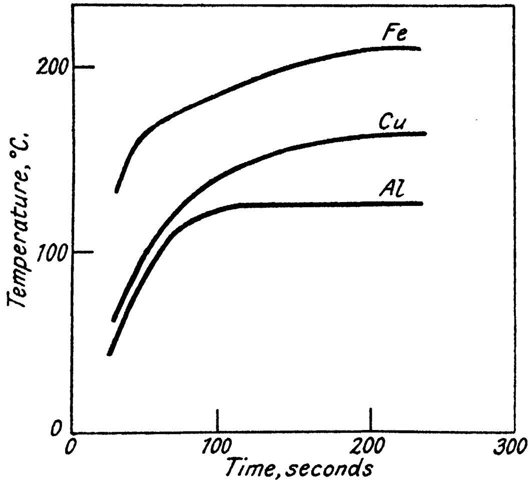

FIG. 94.—Effect of Duration of Spraying on Temperature of Base.

The reason that welding of the individual particles does not occur may be explained as follows :

A particle deposited upon the target in the molten or plastic condition is instantly solidified because of the cooling effect of the air current which immediately begins to rush past it so soon as it adheres to the surface sprayed upon. Furthermore, the target itself when cold exerts a powerful chilling effect upon the deposited particles. This deposition and solidification are so nearly simultaneous that by the time oncoming particles have struck, the particles already deposited are solidified, and the newly arriving plastic particles are merely pressed closely over and into all interstices of the surface upon which they fall, but without welding, since before welding

FIG. 95.—Tin Sprayed on to Cold Glass. × 50.

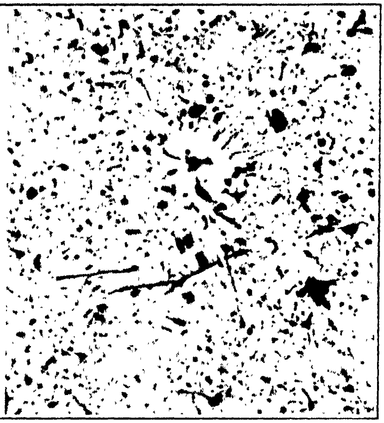

FIG. 96.—Tin Sprayed on to Glass Heated to 400° C. × 50.

FIG. 97.—Lead Sprayed on to Cold Glass. × 50.

FIG. 98.—Lead Sprayed on to Glass Heated to 400° C. × 50.

can occur both pieces to be united must be in the plastic or molten condition, whereas in this case only one of them is. Necessarily the distances of the particles from one another in the transporting blast are not at all equal. If, as is quite possible, any two particles one behind the other are so near to one another in the transporting blast that they fall upon the target almost simultaneously, then they naturally weld together, since they are both in the same plastic state, and form one particle recognisable as such with the aid of the microscope. But then one could not say whether the particle fell as one individual or was formed by the union of two particles so close together in the transporting blast that upon simultaneously impacting they coalesced together to form one. To test the theory that the particles are molten or at least plastic at the instant of impact, Turner and Ballard sprayed various metals separately on to glass slips heated to various temperatures. These were then examined microscopically and photographed at a magnification of 50 diameters, using substage illumination. Some of the shadowgraphs so obtained are shown in figs. 95-111, and seem to indicate by the "splashed" appearance which they exhibit that the metals were in all cases molten or became so at the moment of impact.

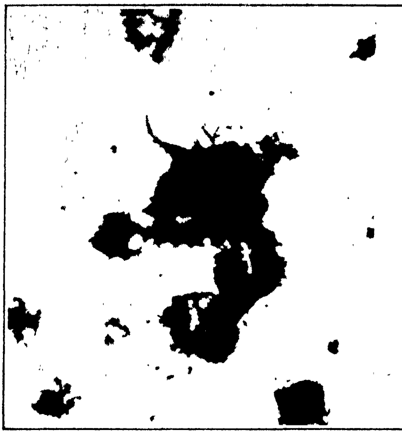

Fig. 99.—Zinc Sprayed on to Cold Glass. × 50.

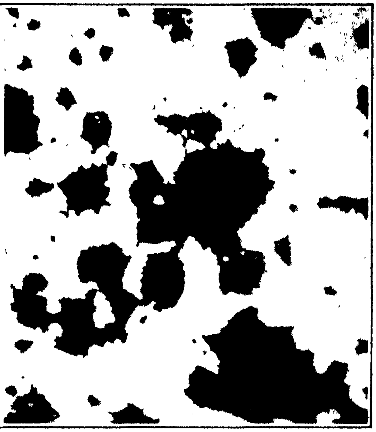

Fig. 100.—Zinc Sprayed on to Glass Heated to 400° C. × 50.

The fact that some of the particles have coalesced into ring-shaped forms would seem to further support the theory. The reason for the formation of the hollow ring type of particle is not obvious, but may possibly be due to the shape or spinning of the molten particle during transport, or to its containing a minute quantity of air and thus being virtually a molten metal bubble which upon impact bursts and lies as a ring upon the surface struck.

The shadowgraphs of metals sprayed upon glass heated to 400° C. are remarkable in that there appears to be less splash in such cases than when the glass slip was cold.

The hypothesis favoured by Rollason is that the particles are melted completely or partially in the flame, depending on the spraying apparatus, and cool fairly slowly while travelling in the air stream, since there is little differential movement of the two materials. When the pistol is held close to the article (1-3 in.) the particles are still molten when they strike the surface. Splashes like fallen drops of solder are formed (fig. 112) and interlock together. At high magnifications the microstructures of these splashes exhibit columnar crystallisation, as shown in fig. 114, with discontinuous oxide films and cavities at the edges of the lamination; these crystals must have formed after the particles had struck the surface. After deposition,

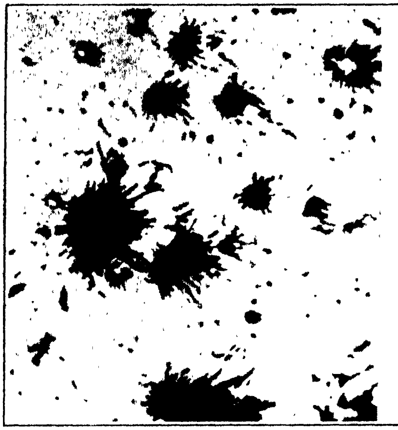

Fig. 101.—Aluminium Sprayed on to Cold Glass. × 50.

Fig. 102.—Aluminium Sprayed on to Glass Heated to 400° C. × 50.

Fig. 103.—Copper Sprayed on to Cold Glass. × 50.

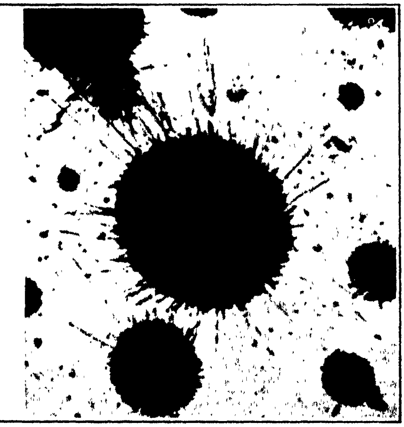

Fig. 104.—Copper Sprayed on to Glass Heated to 400° C. × 50.

the particles are rapidly cooled by the air stream impinging against the surface, and since the base conducts away only a small proportion of the heat, an inflammable material is not ignited by the lower melting-point metals sprayed normally. At greater distances from the nozzle the particles will be cooled below their freezing-point, splashes will not form, but with sufficient kinetic energy the particles will be deformed into a laminated packing enclosing fine pores. At still greater distances the particles form a " heaped " sand-like mass with high porosity (fig. 117).

FIG. 105.—Nickel Sprayed on to Cold Glass. × 50.

FIG. 106.—Nickel Sprayed on to Glass Heated to 400° C. × 50.

FIG. 107.—Iron Sprayed on to Cold Glass. × 50.

FIG. 108.—Iron Sprayed on to Glass Heated to 100° C. × 50.

Structure of Sprayed Metal Coatings.—Sprayed layers are in general so thin that a section cut at right angles to the sprayed surface, and hence parallel to the direction of the spray, gives only a very small field of view for microscopic examination. Turner examined such coatings upon mild steel by mounting the sprayed specimens in a low melting-point white metal before cutting the section, while Rollason used bakelite. Other investigators have prepared sections cut diagonally, in order to increase the field examined. Arnold, in particular, has shown a number of photomicrographs of sprayed metals.*

FIG. 109.—Iron Sprayed on to Glass Heated to 200° C. × 50.

FIG. 110.—Iron Sprayed on to Glass Heated to 300° C. × 50.

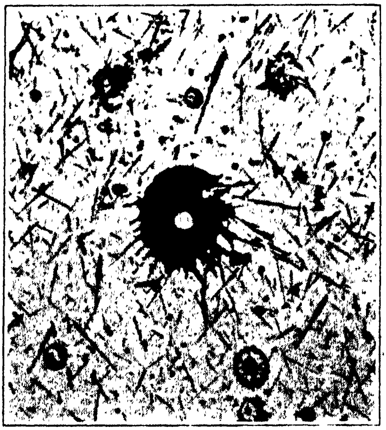

FIG. 111.—Iron Sprayed on to Glass Heated to 400° C. × 50.

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* *Zeit. für anorganische und allgemeine Chemie*, 1917, **99**, 67; also *Met. Ind.*, 1918, **12**, 122.

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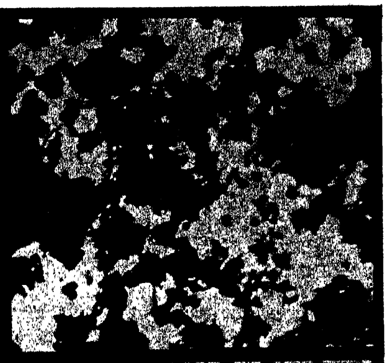

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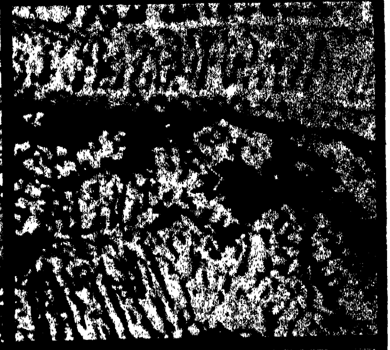

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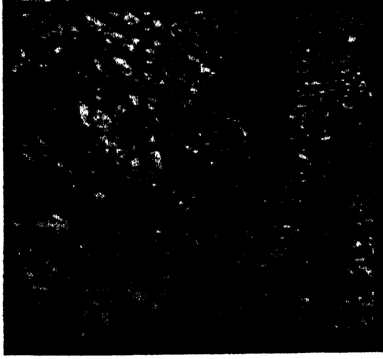

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Fig. 112.—Sprayed Copper on Glass : Wire Process, Transmission Photo. × 50.
Fig. 113.—As Fig. 112, but using Powder Process : No Splash Effect. × 50.
Fig. 114.—Sprayed Copper by French Wire Pistol : 1 in. Nozzle Distance. Columnar Grains across Layers, Etched. × 1000.
Fig. 115.—Same as Fig. 114 but at 4 in. Nozzle Distance. Smaller Columnar Grains with Porosity (↑). × 1000.
Fig. 116.—Same as Fig. 114, but at 9 in. Nozzle Distance. Columnar plus Equiaxed Grains. × 1000.
Fig. 117.—Same as Fig. 114 but at 10 in. Nozzle Distance : Typical Undeformed Particle, Coated with Oxide (↑).

(Rollason).

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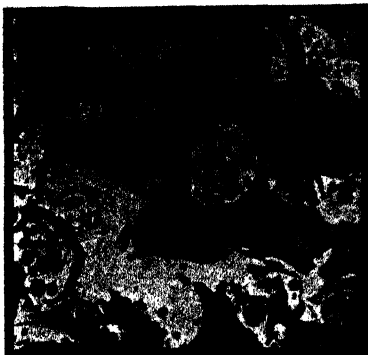

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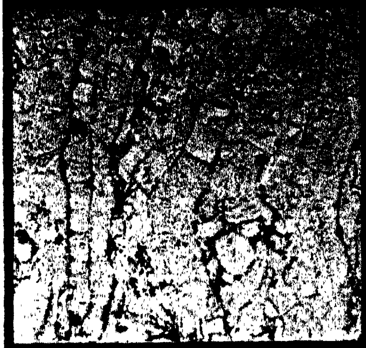

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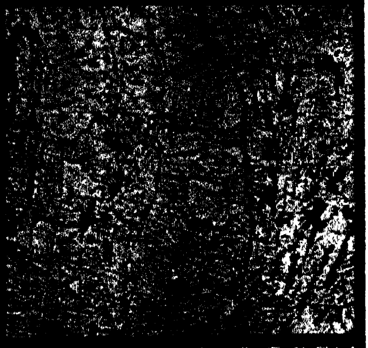

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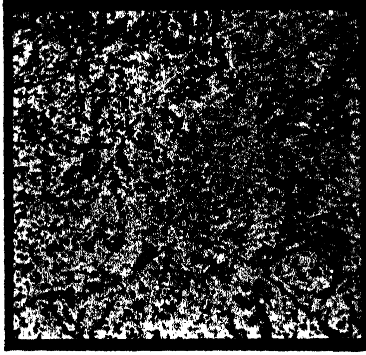

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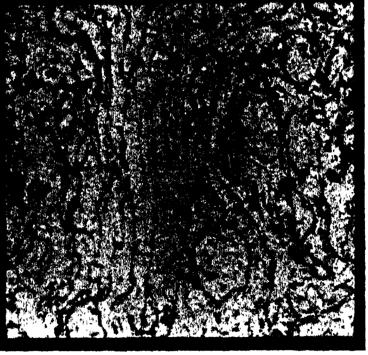

FIG. 118.—Sprayed Copper by Powder Process. Porosity = black; Cu_2O = half-tone; O_2 = 3·4°/$_0$. Etched. × 400.

FIG. 119.—Sprayed Zinc by Powder Process, Normal Distance. Laminations and Round Grains. Porosity 19°/$_0$. Etched. × 400.

FIG. 120.—Sprayed Zinc by English Wire Pistol; Using Acetylene, 1 in. Distance. Columnar Grains. Porosity 8·1°/$_0$. Etched 2°/$_0$ HNO_3. × 400.

FIG. 121.—As Fig. 120, but at 10 in. Distance. Porosity 11·9°/$_0$. Columnar Grains. × 400.

FIG. 122.—Sprayed Zinc by English Pistol Using Coal-Gas at 1 in. Distance. Isolated Oxide and Porosity. Porosity 1·1°/$_0$. Density (Toluene) 6·56. × 400.

FIG. 123.—As Fig. 122, but at 10 in. Distance. Columnar Grains and Round Particles. Porosity 8·7°/$_0$. Density (Toluene) 6·88. × 400. (Rollason).

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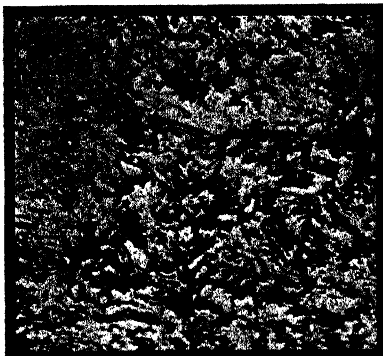

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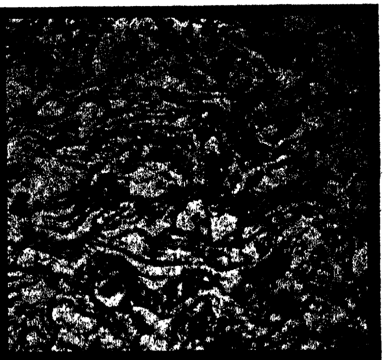

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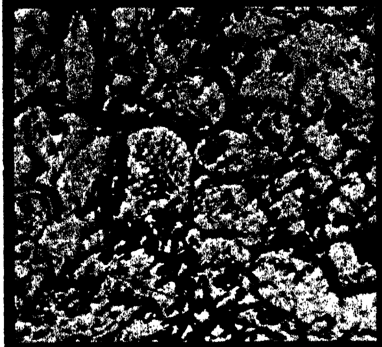

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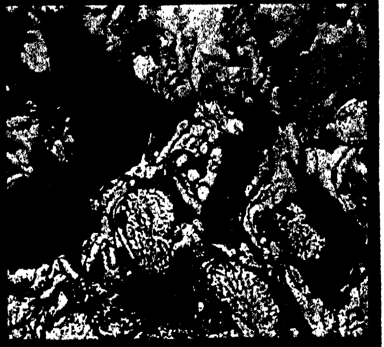

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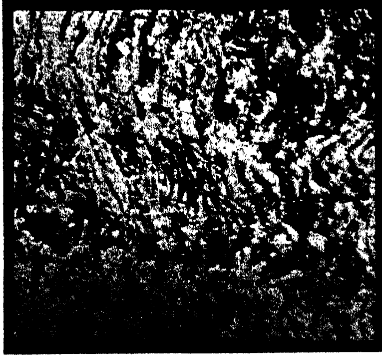

129

C = Sprayed Coat. D = Diffused Layer. P = Base Plate.

FIG. 124.—Zinc Sprayed at 1 in. Nozzle Distance by Molten Metal Process. Note Iron Particle (↑). Porosity 10·6%. × 400.

FIG. 125.—As Fig. 124, but at 5 in. Nozzle Distance. Porosity 11·7%. × 400.

FIG. 126.—As Fig. 124 but at 11 in. Distance. "Heaped" Grain Structure. Porosity 16·5%. × 400.

FIG. 127.—Aluminium Sprayed by Powder Process. Round Particles with Cavities (Black). Porosity 34·3%. × 150.

FIG. 128.—Aluminium Sprayed by English Wire Process. Porosity 8·8%.

FIG. 129.—Sprayed Aluminium by Wire Pistol. Bitumastic Coating. Heated 780° C. for 10 minutes. Etched in HNO_3. × 200. (Rollason).

The structure of sprayed metal when examined in this manner is seen to be crystalline, exhibiting columnar crystallisation.

Rollason recently studied the structures of sprayed coatings. One important difference between the deposits produced by wire and powder processes is shown in figs. 112 and 113 which are shadowgraphs (× 50) of copper sprayed on to glass slips. The powder process does not give the splash effect with high melting-point metals to such an extent as the wire process.

The photomicrographs (figs. 114-128) are all taken from cross-sections through the deposit and plate.

Figs. 114-117 show the change in microstructure as the distance from the nozzle increases in the case of copper sprayed by the French wire pistol.

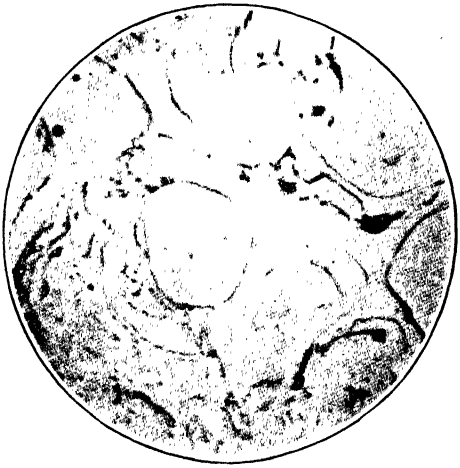

FIG. 130.—Surface Appearance of a Sprayed Metal, Aluminium-sprayed Iron (Arnold). × 250.

A copper coating produced by the powder process is shown in fig. 118 in which the oxide masses are clearly seen; the particles have suffered but little deformation. A zinc deposit, also produced by the powder process, is shown in fig. 119; this again exhibits rounded grains associated with laminated masses. Figs. 120 and 121 show zinc deposits made by the English wire process, using acetylene gas. A high flame temperature is indicated by the columnar crystallisation even at a nozzle distance of 10 in. As a contrast, figs. 122 and 123 show the structure of deposits made with the same equipment using coal-gas as fuel. At a nozzle distance of 1 in. the oxide and pores are dispersed, resulting in a low permeability to liquids. At a nozzle distance of 10 in. a number of rounded particles can be seen in the structure, and the interconnected porosity has increased. This pistol is at its maximum efficiency when using coal-gas, and the flame is consequently more oxidising than when acetylene is employed.

Figs. 124, 125 and 126 show the structure of zinc formed by the molten metal process. At a distance of 11 in. the structure consists essentially of "heaped" masses of particles, resulting in high porosity, whilst at 1 in. numerous unetched particles of an elongated shape are found in the structure. These are possibly iron or iron-rich material abraded from the nozzle.

The structure of an aluminium deposit made by the powder process is shown in fig. 127. It consists almost entirely of rounded particles of metal each possessing a dendritic structure, and enclosing many pores. The structure produced by the wire process is much more laminated (fig. 128).

The most characteristic feature of the structure of sprayed metal is the undulating contours of the sprayed particles themselves. At the moment of impact the particles flatten out into elongated flakes which are frequently bent into corrugations. The undulations can only be discerned in transverse or longitudinal sections, the particles when viewed from the front appearing as round flakes, grouped in irregular superposition like a row of plates lying one upon the other. The face view of sprayed aluminium is shown in fig. 130. The true grain-size of sprayed coatings is normally very small, as is well illustrated by back reflection X-ray photographs (fig. 131) which in the case of zinc, aluminium and copper always show continuous rings, resolved doublets, and a considerable background due to slight cold-work and to oxide particles.

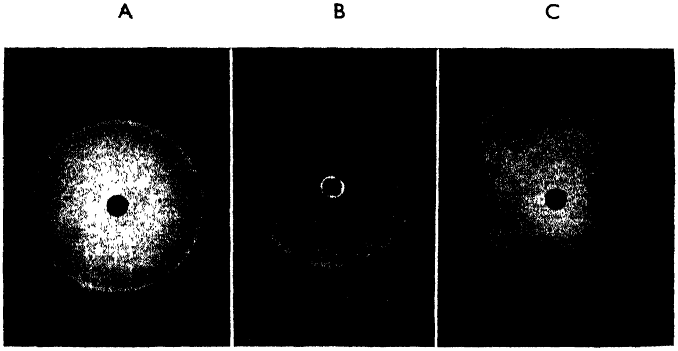

FIG. 131.—Back Reflection X-ray Photographs of Sprayed Metals:—A = Copper, Wire Process; B = Aluminium, Powder Process (note spots on rings); C = Zinc, Wire Process.

(Rollason).

Adhesion of Sprayed Metal Coatings.—In hot galvanising or tinning, the molten zinc or tin flows over the cleaned surface of the object to be coated entirely, " wetting," and to some extent alloying with the foundation metal. In sherardising and calorising the coating metals employed, zinc and aluminium respectively, are in the form of powder, and by the application of heat during the period of their close contact with the object to be metallised an alloy layer is formed.

In the above cases, the reason for the adhesion of the coating to the substratum is due mainly to the alloying which takes place, and, as a result, the coating metal adheres very firmly since it has in fact become part of the object metallised. In electro-plating, metallic particles of atomic dimensions are deposited from solution upon the surface to be coated, and unless special treatment (such as previous dipping in mercury salt solutions*) be employed no alloying whatever occurs. The coatings are adherent because the minute metallic particles enter and fill the smallest "pores" of the substratum, thus forming "roots" which anchor the whole coating. In metal spraying the coatings are built up of minute, but not atomically small, particles which, continually ejected from the nozzle of a wire melting, pulverising and projecting pistol, are firmly deposited upon the body to be coated, thereby forming a compact mass. The mechanism of adhesion in this case when spraying almost cold surfaces is certainly similar to that occurring in electro-deposition; even when the surface being sprayed is sufficiently heated, alloying does not occur owing to the scorching of the particles. The conduction of heat between the sprayed coating and the base is not so good as in the case of an alloy.

The following suggestions as to the mechanism of, and correct conditions for, firm adhesion of the sprayed metal were advanced by Robert Hopfelt, Director of the Metallisator A. G. Altona, and appear to be of considerable interest in this respect. It is well known that ethereal substances, such as perfumes, adhere for a long time to bodies moistened with them, and even after repeated washings the human skin still retains sufficient of the perfume as to be easily detected. This is probably to be accounted for by the perfume being "thinner" than water, and therefore able to enter deeper into the pores of the skin than the water used for washing, which thus only removes the perfume from the outer surface.

Two smoothly polished and flat glass or metal plates laid one upon another can be readily separated even though they be first firmly pressed together. If now the plates are either wetted or warmed and then pulled apart it is noticeable that they hold much more tightly together. The explanation lies, according to Hopfelt, in the fact that wetting removes the adhering layer of air from the surfaces and permits of their closer contact, warming acts similarly by causing expansion and hence partial expulsion of the intermediate air layer. Thus, if it is desired to secure a firm adhesion between the two plates, they must be strongly heated whereby the air cushion is largely removed. This principle applies in the autogenous welding of metals at high temperatures. In this case, however, it is also necessary to press the pieces firmly together so as to break through the oxide film which forms and thus bring the metals sufficiently closely in contact for union to occur. In a similar manner bodies are soldered together, and for this process fluxes are used to remove the separating oxide layer.

It is evident from the above that one of the essentials for adhesion of sprayed metal is that no air layer be allowed to remain between the particles forming the coating and the substratum.

It was thought to be advantageous to maintain the article during spraying at an elevated temperature in order to effect expansion and partial removal of the adhering and occluded air layer, but recent practice has shown that scorching and oxidation troubles arise. Welding may take place if a very short nozzle distance is used, but the deposit is so rich in oxide that it is

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* This prior treatment is recommended in the older text-books on electro-metallurgy for such metals as copper, brass, and nickel silver which are to be silver-plated. A very thin film of mercury forms and alloys both with the object to be plated and with the silver coating when this latter is deposited.

useless for most practical purposes. If a metal particle, which is surrounded by a certain amount of air, strikes in a heated condition upon a smooth metal plate, it makes a gliding movement before coming to rest. Since this requires a certain amount of time the particle will cool. More air approaches it and thus cancels the heating effect. The particle will then, during its gliding movement, rise from the surface again and describe a path as in fig. 132.

A metal deposit on a smooth surface will hence appear as in fig. 133.

The coating touches the substratum only at a few points, so that inferior adhesion is obtained.

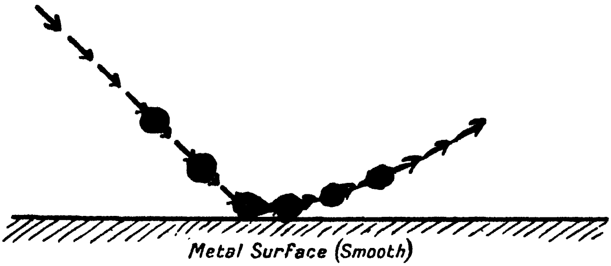

FIG. 132.—Diagram to show how a Metal Particle may Strike, Glide Along, and Leave a Smooth Surface. (According to Hopfelt.)

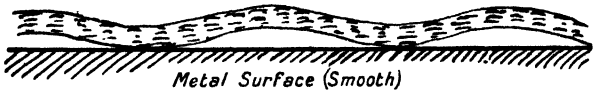

FIG. 133.—Diagram to illustrate the Type of Deposit Produced by the Action shown in Fig. 132. (According to Hopfelt).

FIG. 134.

If now the substratum is previously sand blasted, the surface is roughened and sharp elevations and depressions are produced side by side. A metallic particle projected against such a surface immediately comes to rest, and the heat with which the grain was charged is fully utilised for the expansion and removal of the air surrounding it. The sudden cessation of the movement of these particles produces more heat, further improving the chances of adhesion. Thus a metal layer sprayed on to a sand blasted surface firmly anchors itself to the foundation and comes into more intimate contact with the surface than when it was smooth (fig. 134).

Subsequent heat treatment also facilitates the formation of an alloy layer. The adhesion of aluminium coatings is considerably increased by heating to a red-heat whereby an intermediate layer of alloy is formed.

A further factor of influence upon the adhesion is the fineness of grain of the coating. Small particles are able to penetrate more easily into the pores of the surface than are coarse ones, and the danger of the holes being simply bridged over is less when using a fine spray. The fineness of the metal spray depends primarily upon the air pressure by which the metal is projected, upon the position of the burner, and finally upon the resistance of the object to be coated. That the spray actually becomes finer the harder and more rigid the foundation is probably untrue. P. Nicolardot in Paris has examined these conditions carefully and illustrated his reports by very instructive photomicrographs.*

On glass or quartz surfaces excellent adhesion is obtained if the body is heated to 700° C. immediately before spraying; with sprayed aluminium or copper separation is only possible by using considerable force, and the metal coating when broken off has torn with it a great number of little glass splinters. The coating of glass demands a certain amount of care and practice, whereas, on the contrary, quartz may be easily coated both firmly and evenly.

In general, objects to be sprayed, such as porcelain, quartz, enamel and such like, are subjected to a preliminary "matting" of the surface by means of a very fine quartz sand blast. In the case of glass the surface is covered with a coat of gelatine or bakelite, which is allowed to dry before spraying. The roughened surface of a piece of steel which has been sand blasted and sprayed with bronze is shown in fig. 135 in section, magnified 100 diameters. The surface is very irregular, and distortion of the steel crystals has occurred during the sand blasting.

A further point of interest is the flint particle from the sand blast fixed like an arrowhead in the cavity about the centre of the illustration.

It will be evident that such drastic roughing constitutes a drawback in many instances for technical and art work, so that a finer grain of metallic particles necessitating less roughened surfaces would be a desirable feature. If the coating be thick it sometimes separates too readily from the substratum, This is a circumstance which has given rise to serious objections in practice. Owing to the temperature of the metallic particles being always higher than that of the substratum, the different rate of expansion and contraction constitutes a disturbing factor, and may partly explain the trouble experienced by unskilled metal sprayers in repairing defective places.

The roughening, which in practice is somewhat of a disadvantage, is nevertheless quite indispensable, even with wood and millboard. It should also be understood that the natural grain of wood will be made to stand out in relief by sand blasting. Not every kind of paper is suitable for metallising; papers with a coarse fibre or unglazed finish give excellent results.

The difference in coefficients of expansion of non-metallic objects is an important point, since after the slightest heating the metal contracts more than the foundation material. In metallising a wooden surface, for instance, with aluminium, it is found, in spite of the previous roughening, that the coating frequently detaches at the edges on cooling and curls up. On this account it is necessary to spray over the edges as much as possible in order to give the coating a hold. From this, however, it will be evident

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* "Les Progrès récents dans la Préparation des Moulages et des Revêtements métalliques," *Bull. Soc. d'Encour.*, December, 1913.

that there is the risk that when this hold is loosened through a fragment being broken out at the edges, for instance in polishing, the whole coating or much of it may come off. This would explain why the metallisation of aeroplane propellers has not become so universal as might well have been expected. For some unknown reason the adhesion of sprayed copper on hardened high speed steel is very poor.

Measurement of Adhesion.—The fixedness or adhesion of metal deposits on their under-surfaces is of especially great importance in practice, altogether irrespective of the methods of coating. In general, metal coatings for industry are more valuable the less liable they are to chip off by mechanical usage, or to develop holes on polishing. The adhesion of a coating to the foundation metal is tested in practice, with zinced iron, for example, by bending the sheet backwards and forwards and noting how often this may be done without the surface layer being loosened. With zinced wires (according to the regulations of postal and telegraph authorities), the adhesion is determined by winding the wire in a close screw thread or round a cylinder ten times the cross-sectional area of the wire, during which the zinc coating may neither develop cracks nor become loose. Such tests, rough as they are, give for purposes of comparison thoroughly practical and reliable data. With sprayed layers, therefore, similar bending tests were tried and gave quite satisfactory results. We may mention that, for example, a layer of zinc sprayed upon copper could be broken, it is true, by violent bending backwards and forwards and by heavy hammering, but a separation of the copper and zinc only occurred much later. Comparative experiments performed to ascertain the adhesion of coatings sprayed on to test pieces which were subsequently stretched have also given interesting results.

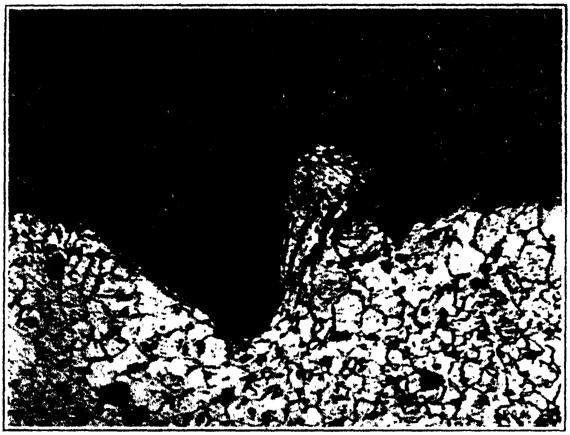

FIG. 135.—Sand Blasted Steel, Bronze-sprayed (Turner). × 100.

Rods sprayed with zinc only show small cracks on stretching after 19 per cent. elongation, whereas with otherwise completely similar pieces galvanised, the coating cracked off with 11 per cent. elongation. Furthermore, the sprayed specimens could be bent double until their ends touched without the coating being loosened, but galvanised specimens could only be bent to an angle of 130°.

The apparatus illustrated in fig. 136 was used to study more accurately the adhesion of sprayed layers and the conditions influencing such adhesion. In fig. 137 is shown a strong metal plate *a*, through the middle of which a peg *b* can be pushed just so far that it lies accurately flush with the surface of the plate. The peg *b* is interchangeable, and consists of whatever metal is to serve as the foundation for the layer *c* to be examined.

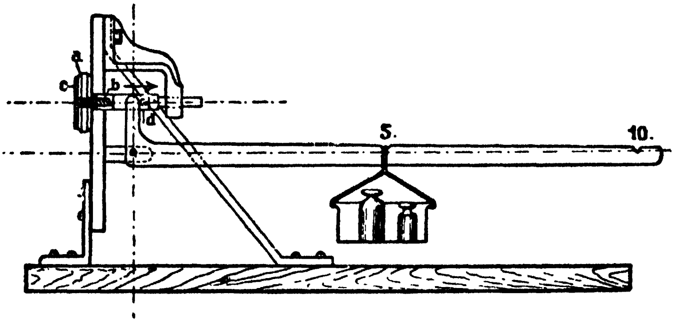

FIG. 136.—Apparatus for Measuring Adhesion of Sprayed Metal Coatings (Schoop).

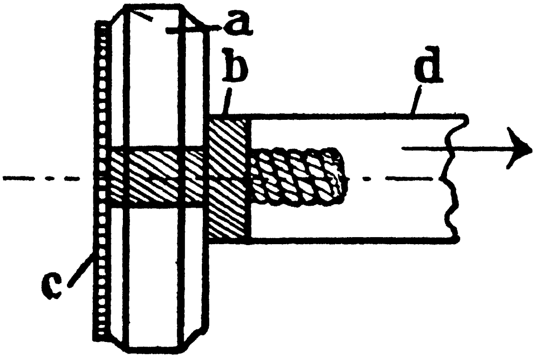

FIG. 137.—Enlarged Detail of Part of Fig. 136.

This layer is sprayed on to plate *a* after the peg *b* has been pushed in position. As fig. 136 shows, the apparatus is so arranged that the peg *b* may be torn off by means of a loaded right-angle lever, while the plate *a* remains firmly fixed. The lever grips with its short vertical arm the stop *d*, which constitutes an extension of the peg *b* and is screwed firmly into it. The long horizontal arm of the lever carries a balance scale whose loading may be gradually increased until the weight is just so great that its tension overcomes the adhesion between the peg *b* and the coating, whereupon the peg is torn off. In order to simplify the calculation, the horizontal arm of the lever is arranged to be either 5, 10, or 15 times as long as the vertical arm, and the end surface of the peg *b* exactly one square centimetre in area; it is then only necessary to multiply the weight required to tear off the peg by 5, 10, or 15 in order to obtain immediately the adhesive strength per unit of area.

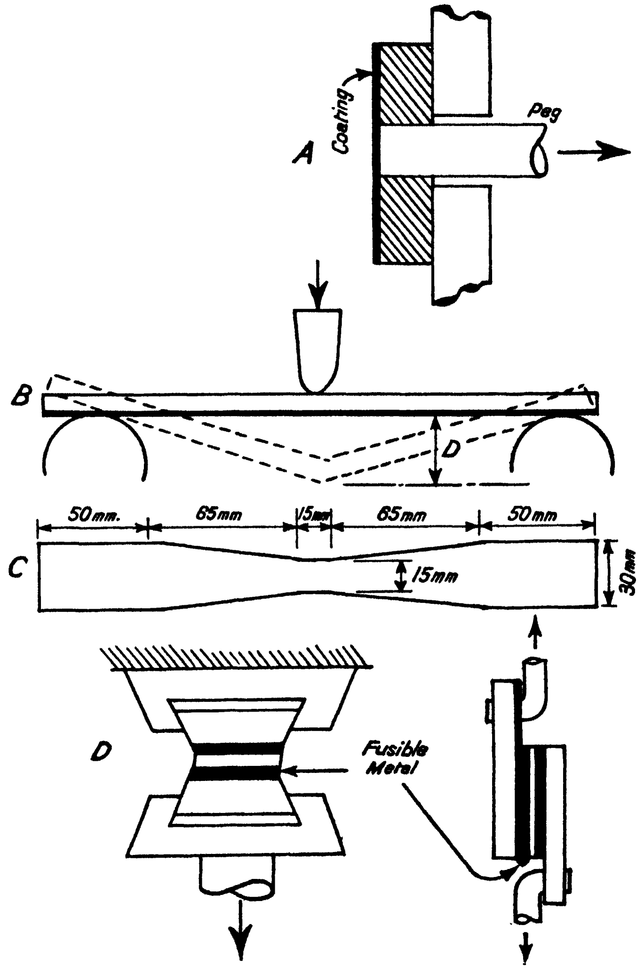

FIG. 138.—Forms of Test for Estimating Adhesion.

Other methods of estimating adhesion are illustrated in fig. 138. B shows a bend test in which the deflection required to crack the coating is measured.

In D (right-hand) the shear stress required to strip the coating from the base is measured, while D (left-hand) is similar to Schoop's method of using direct tension. Two coatings are sprayed and these are joined by means of a fusible metal (*e.g.* Wood's metal). In C is shown a method in which a tensile specimen of mild steel is sprayed with metal and the composite specimen is broken in a tensile machine. The distance which the cracks extend along the specimen is used to indicate relative adhesion.

In 1933 Schenk[*] investigated the relation between the adhesion of the coating, the distance of the nozzle from the base and the speed of the

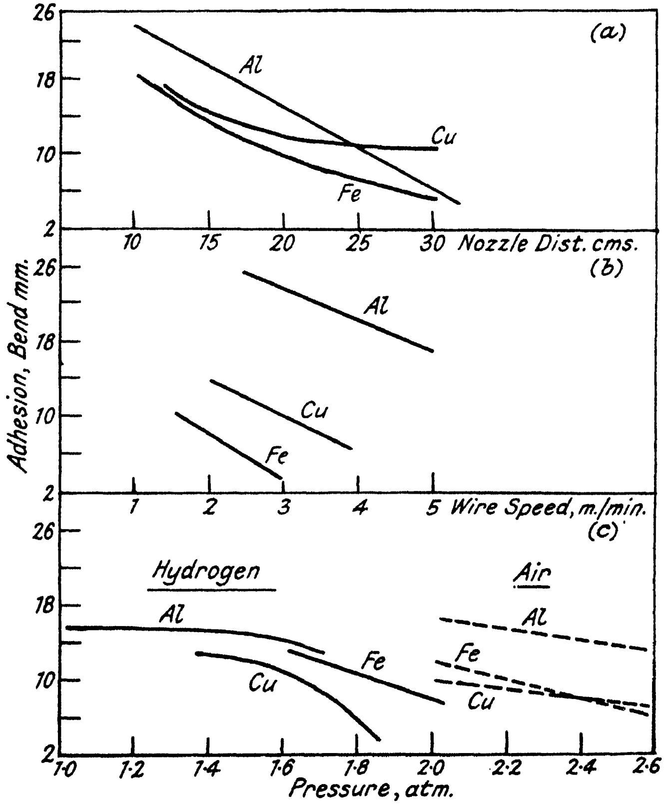

FIG. 139.—Effect of Nozzle Distance, Wire Speed and Gas Pressure on Adhesion of Deposits Sprayed from Wire (Thormann).

feed by measuring the force required to tear away the coating. Thormann attempted to measure adhesion by alternating stress tests, but in all cases the bar broke before the coating had become detached from the base. He finally employed a bend test, taking the radius of the bend in mm. to cause cracking of the coat as a measure of adhesion.

With a 0·2-0·3 mm. coating made with a wire pistol the adhesion is reduced as the ***nozzle distance*** is increased (fig. 139) owing to the inability of the solidified particles to penetrate the smallest pores on the surface

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[*] G. Schenk, *Werkstattstechnik*, 1933, **27**, 231.

of the object. With slower *wire feed* the adhesion is reduced on account of the increased particle size. Increased *hydrogen pressure* and *air pressure* also decrease the adhesive property.

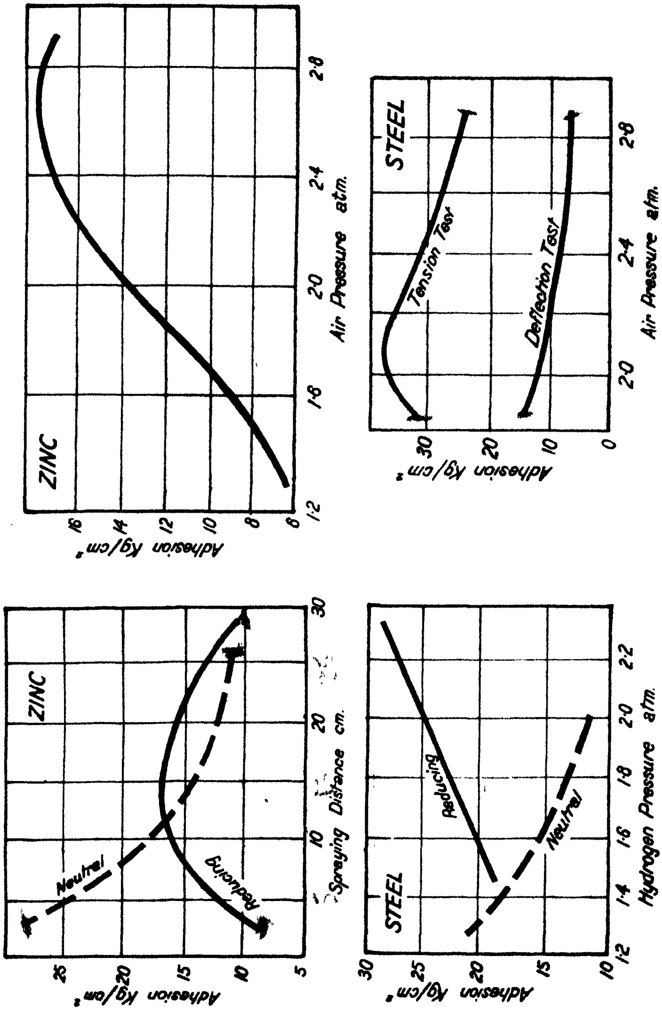

FIG. 140.—Effect of Spraying Conditions on Adhesion (Everts).

The spraying conditions which Thormann found to give the best properties in the coating are given in Table IX.

Everts recently published* the results of some experiments on the adhesion of coatings of zinc, steel and V. 2 A. steel, sprayed according to German practice. Optimum adhesion appeared to be obtained by sand

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* *Zeit. Metallkunde*, 1937, **29**, 63.

TABLE IX.—*Spraying Conditions which give the Best Properties (After Thormann, using Wire Pistol).**

	Nozzle Distance, cm.	Feed, m./min.	Hydrogen Pressure, atm.	Oxygen Pressure, atm.	Air Pressure, atm.
ALUMINIUM.					
Adhesion	15	3·5	1·5	1·2	2·2
Efficiency	15	5·0	1·2	1·1	2·0
Density	20	5·5	1·3	1·2	2·2
Hardness	10-15	6·0	1·6	1·6	3·0
COPPER.					
Adhesion	15	2·5	1·4	1·3	2·2
Efficiency	15	4·0	1·4	1·3	2·0
Density	20	3·0	1·6	1·5	2·2
Hardness	10-15	4·5	1·8	1·8	3·0
IRON.					
Adhesion	15	2·0	1·6	1·5	2·2
Efficiency	15	2·5	1·6	1·5	2·0
Density	20	2·0	1·8	1·7	2·2
Hardness	10-15	3·0	2·0	2·0	3·0
Wear resistance	30	3·0	1·2	1·1	3·0

blasting the base metal with a coarse sand and subsequently pickling in hydrochloric acid. The effect of conditions of spraying on adhesion were studied and a few curves are reproduced here in fig. 140. It will be noted that the type of curve varies very much according to the character of the flame and also whether bending or tension tests are employed. The study of the influence of variables in the spraying conditions leads to the following recommendations for the production of adherent coatings :—

TABLE X.—*Spraying Conditions for Best Adhesion (German Practice).*

Metal.	Spraying Distance, cms.	Hydrogen Pressure, atm.	Oxygen Pressure, atm.	Compressed Air Pressure, atm.	Wire Feed, m./min.
Zinc	15	0·7	0·6	2·4-3·0	4·2
Steel	20-25	1·8	1·7	2·1	1·8
V. 2 A. Steel	10	2·5	2·5	3·0	2·3

The optimum spraying conditions for steel do not agree entirely with those given by Thormann (Table IX), and the use of a hydrochloric acid pickle is certainly contrary to general practice. The reason for this may be found in the use of Wood's metal (fig. 138). The coatings may be sufficiently porous to allow the Wood's metal to penetrate to the base and the pickle enables the coating to be soldered to the base with consequent high adhesion.

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* These results are for German practice, using hydrogen, which is known to require different conditions from coal-gas as used in England. The spraying distance, in particular, is rather great.

TABLE XI.—*Results of Tests on Adhesion of Sprayed Coatings (Fassbinder and Soulary).*

Metal and Process	Breaking Load, kg.	Distance to Cracks, mm.	Stress at Cracks, kg./sq. mm.	Scratching Limit, mm.	Stress at Scratching Limit, kg./sq. mm.	Remarks
ZW 1	870	115	29	125	31	Partial adherence in cracked zone.
ZW 2	875	113	29	128	31	,, ,,
ZW 3	875	113	29	122	31	,, ,,
ZP 2	950	114	32	111	30	,, ,,
AW 2	950	97	32	100	32·5	,, ,,
AP 2	875				Coarse easily sc	and whole deposit raped off.
BW 2	1075	82	29	85	30	As ZW 1.
CW 2	975	99	26	105	28·5	,,
SW 2	1050	102	29	104	30	,,

Z. Zinc. S. Stainless 18/8. A. Aluminium.
B. Brass. W. Wire process. P. Powder process.
C. Copper. 1, 2, 3. Number of layers 0·04 mm.

Fassbinder and Soulary studied the adhesion between metallised deposits and mild steel by coating tensile specimens of steel shaped as in fig. 138C, followed by fracturing the specimens. It was then ascertained how far from the ends of the two stumps the first cracks could be seen and at what distance it ceased to be possible to remove the coating by scratching with a hand tool. Table XI shows the results of these tests, using acetylene as fuel gas, air at 4 kg./sq. cm. for projection and a nozzle distance of 7 inches. The number of layers had no great effect on the results. The scratching test showed that the coatings made by the wire-fed pistol possessed a higher intrinsic tenacity than those produced by the powder pistol, although this depended to some extent on the type of powder. The results shown in columns 4 and 6 indicate that cracking of the coatings did not visibly arise until the stress in the mild steel reached a value within the order of magnitude of the elastic limit of the steel. It follows that mild steel components subject to loads which are generally much below their elastic limit can be effectively protected in service by sprayed coatings without risk of cracking or peeling owing to deformations in the base metal.

Improvement of Adhesion by Doping.—It is practically impossible to use materials for coatings with the same modulus and limit of elasticity as the base metal and the same limiting values for stretch in a static experiment, as well as identical thermal properties. Therefore, even small mechanical stresses or changes of temperature applied to the metal are liable to cause the coating to peel away from the base. One possibility of reducing this defect is by " bridging " the gap between the properties of the coating and those of the metal by intermediary layers with properties lying midway between those of the base and the coating. Recently also (1935) Reininger has suggested impregnation of the coating with a linseed oil copal varnish or bakelite varnish of high plasticity, which acts as a kind of " buffer " between the coating and the base. In these experiments hard brass was chosen for the base and nickel for the coating. The base had a high elastic limit and the coating a coarse grain, which splits off more readily than fine grain deposits but is more suitable for absorbing the varnish. The liquid varnish enters the capillaries between the particles and, on drying, forms an efficient cement, filling up the cavities between the grains. Micro-structures frequently indicated that the varnish-treated specimen had a coarser structure than the normal coating. This deceptive result was due to the fact that polishing tends to fill up the pores existing in the normal deposit, but the varnish prevents such distortion of the grains in the same way as in bakelite mounting of specimens.

A single bending of an untreated coating produced complete splitting off of the coating, while a similar sample treated with copal varnish, dried for 3 days and bent, exhibited no fissures and much less splitting off from the base.

In stretching tests little difference was shown to exist between normal and varnished samples. Above 5 per cent. elongation all samples showed cracks, but at higher elongations the untreated coatings flaked off in small pieces, whereas the varnished deposit fell off in large pieces. Reininger explains the difference between stretching and bending tests as due to the forces separating the coating from the base exceeding the critical values of adhesion, despite the difference which exists in the cohesion of the deformed coatings.

A further demonstration of the different adhesive strength can be given by gradually grinding the coating off the base. Single particles are torn from the structure of the non-varnished coating and the surface of the section is rough. In the case of the varnished coatings no tearing out of macroscopic grains was observed and the coating could be ground down to a very thin layer without splitting from the base. Ballard and Harris also found that heavily oxidised specimens can be cut with ease in the lathe and they have suggested that the oxide may act in a similar manner to varnish impregnation.

On exposure to water, salt, or acid solutions, the varnished coatings were resistant and electro-chemical corrosion due to the formation of galvanic couples at the junction of the base and the coating is prevented. Organic solvents (alcohols, acetone, turpentine, linseed oil) destroy the varnish layers. On the other hand, experiments* in England have shown that coatings to which stoving enamel had been subsequently applied showed greater deterioration than did those carrying sprayed coatings of aluminium only.

The use of the powder pistol opens up possibilities of spraying mixtures of powdered glass and metal, in which case the glass may fill up the pores in the zinc coating and also increase the bonding.

Cohesion, Adhesion, Strength, and Thickness of Sprayed Metal.—Cohesion is the sticking together as in a mass of the individual particles of the coating itself as distinguished from the adhesion of the coating as a whole to the substratum. The thickness of sprayed coatings is in no way limited, they may be sprayed as thinly or thickly as desired from the merest film up to several centimetres. For rust-protection a coating 0·004 in. is generally sufficiently thick. However, in considering or testing the strength of a coating, its thickness must be taken into account. With thin coatings the cohesion is relatively slight, whereas the adhesion of each part on to the substratum is much greater. If, on the other hand, the coating is applied so thickly that it forms a coherent metal surface,

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* The Fifth Report of the Corrosion Committee, Iron and Steel Institute, 1938, 397.

then with the higher melting-point metals the cohesion is considerably greater than the adhesion, with the more fusible metals such as tin and lead the cohesion of the coating, even with thick layers, is comparatively small so that the adhesion is again greater than the cohesion. With brass, copper, bronze, iron, and nickel, however, as soon as a coherent coating is obtained the cohesion becomes considerably greater than the adhesion.

The metallic coatings produced by spraying form a kind of metal millboard, the individual particles of which are, as it were, felted or matted together. The thickness of non-magnetic sprayed coatings on a steel base can be readily measured by a G.E.C. layer thickness meter. The coating forms the gap in the magnetic circuit of a small transformer contained in an exploring head. Through the primary of the transformer a constant current is passed, and the voltage induced in the secondary winding is indicated on the meter. The voltage is proportional to the thickness of the coating, which can be obtained from a calibration chart.

Oxide Content, Permeability and Density.—In the literature on the subject there are many different opinions regarding the oxide content of the sprayed deposit. Schoop, Arnold and Bablik consider that no oxidation of the particles in flight occurs except when a highly oxidising flame is employed. Reininger, Parkes and Karg admit the presence of oxide in the coating, but no values are given. Recently, however, values for sprayed copper have been obtained by Ballard and Harris and also Rollason. Their results are discussed later in this section. Sprayed coatings are, according to Hopfelt, almost completely free from metallic oxides, and this he explained as follows :—

The reaction between a chemical element and oxygen (*i.e.* the oxidation or burning of a body) is dependent upon three conditions :—1. the proportions of the two substances ; 2. the ignition temperature ; 3. the time during which combustion may occur.

Now in the melting flame of the pistol little or no free oxygen is present, so that only by the dissociation of steam is combustion of the metal possible. Such secondary action is, however, less effective and takes place very slightly. The air envelope is, on the other hand, rich in oxygen.

The temperature of the flame is so high that ignition certainly would be possible if the other two conditions were fulfilled. The time available is not, however, sufficient for the occurrence of the reaction, so that oxidation cannot proceed. The speed at which the metallic particles are projected through the flame amounts to about 300 metres per second, so that the individual particles are only in the zone of highest temperature for 1/10,000th of a second. Outside the flame the speed is certainly less, but here the temperature is considerably lower and would not be high enough for oxidation of the metal. It has been claimed that metallic coatings from lead and zinc up to iron are almost completely free from oxide. Arnold, writing on the subject of density of sprayed coatings, says quite rightly that the only comparison of value is with cast metal. The comparative experiments set forth in the following Table XII were performed by cutting and polishing the sprayed metals on all sides so as to obtain a perfectly smooth surface, the specific gravity being then determined in the usual manner by immersion or with the pyknometer. Apparently no precautions were taken to prevent absorption of water during the experiments.

TABLE XII.—*Specific Gravities of Sprayed Metals according to Arnold (Wire Process).*

Metal.	Figures Obtained.	Sprayed Metal.	Cast Metal.
Tin . .	6·820 6·809 6·837	6·82	7·286
Zinc . .	6·236 6·300 6·250 6·514	6·325	6·922
Bronze .	7·81 7·771 7·749	7·77	8·76
Brass .	7·237 7·526 7·209 7·323	7·324	8·299
Aluminium .	2·262 2·335 2·309 2·344	2·31	2·54
Lead .	9·764 9·768 9·750 9·812	9·776	11·362
Copper .	7·536 7·532 7·809 7·122	7·51	8·933

These determinations indicate that the sprayed metal contains cavities and gas inclusions and probably a considerable quantity of oxide, the value in the case of sprayed copper being 16 per cent. lower than that of the cast metal. The fluctuations in the individual values also show that the structure varies in spite of the identical methods of production. Annealing *in vacuo* increases the density, especially in the case of copper, the value for which is raised to 8·11. Turner and Ballard have also given figures which they obtained from bars of sprayed metal, and their results are given in Table XIII.

TABLE XIII.—*Specific Gravities of Sprayed Metals (Wire Process). (Turner and Ballard).*

Metal.	Pure Metals. Hoyt's Figures.	Sprayed Metal. Turner and Ballard's Figures.	Sprayed Metal. Arnold's Figures.
Aluminium .	2·56	2·4	2·3
Zinc . . .	7·0	6·4	6·3
Tin . . .	7·3	7·1	6·8
Iron . . .	7·86	6·5	...
Copper . .	8·65	8·0	7·5

When one considers the nature of the material, built up as it is of interlocked particles, each of which might have been oxidised, the low density figures are no longer remarkable. One may indeed be surprised that they approximate so closely the figures obtained on cast metals. The fact that Turner's figures are somewhat higher than those obtained by Arnold is probably due to improvements recently introduced into the technique of metal spraying.

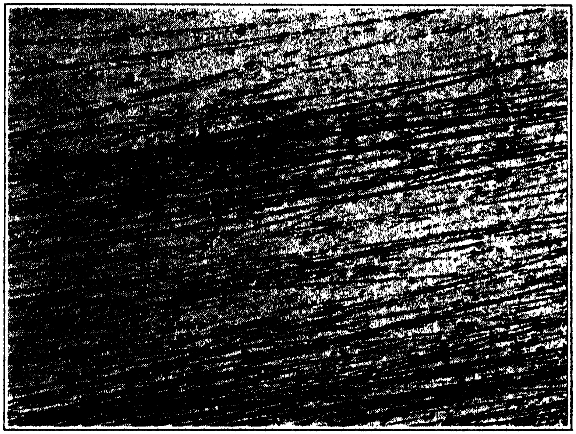


FIG. 141.—Sprayed Copper, Rough Polished (Turner). × 100.

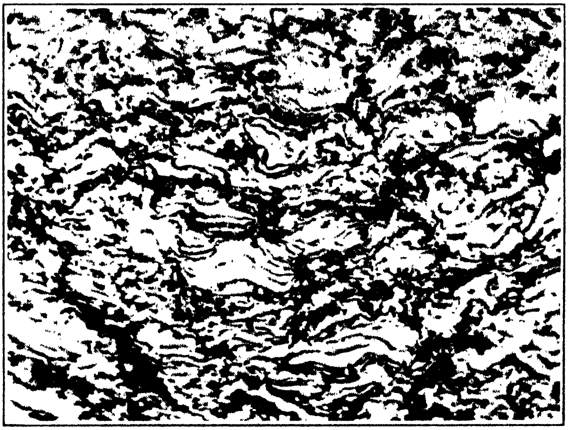


FIG. 142.—Cross-section through Sprayed Copper, Etched with Ammonia; note inclusions of Cu_2O (Turner). × 100.

The assumption that a certain amount of oxidation takes place in the spraying process has been confirmed by experiment. Copper is a particularly suitable metal for this purpose, the oxide content being readily detected under the microscope by the well-known blue beads of cuprous oxide. If a piece of sprayed copper be polished, without etching, a smooth, bright surface is

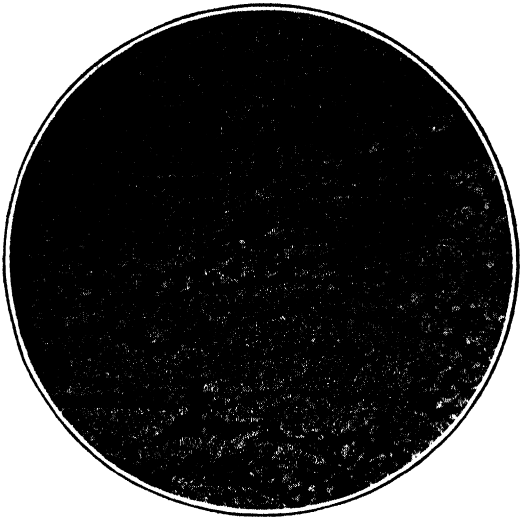


FIG. 143.—Cross-section through Sprayed Copper Annealed at 800° C. *in vacuo* (Arnold). × 100.

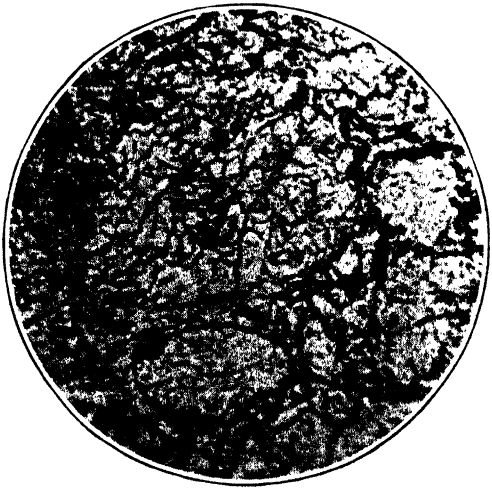


FIG. 144.—Surface of Sprayed Brass (Arnold). × 1200.

obtained on which nothing can be observed other than the usual polishing scratches (fig. 141); but if the section be etched with a little ammonia in polishing, inclusions of cuprous oxide are at once rendered visible (fig. 142).

The structure is clearly developed by annealing the specimen in a high vacuum.

Fig. 143 shows a piece of sprayed copper annealed at 800° C. *in vacuo*. By progressive heating *in vacuo* the blue inclusions of cuprous oxide appear more and more clearly along the undulations; and above 500° C. the oxide begins to coalesce into fine globules.

Figs. 144 and 145 are photographs of brass and bronze, the individual structural components of which are also interesting. Brass, for instance, is deposited by the spraying process as β-brass.

FIG. 145.—Sprayed Bronze after Annealing at 500° C. *in vacuo*; Solid Solution (Arnold). × 700.

The estimation of oxygen in most metals offers experimental difficulties, with the exception of copper. A few typical values for copper are given in Table XIV, from which it will be seen that the powder pistol produces highly oxidised copper coats.

TABLE XIV.—*Percentage Oxygen in Copper Deposits* (*Rollason*).

	Nozzle Distance, Inches.	Oxygen, Per Cent.	Cu_2O, Per Cent.
Powder pistol	8	2·84	25·6
,, ,, ...	10	3·39	30·6
,, ,, ...	12	3·17	28·4
American wire . . .	3	1·72	15·4
English wire	3 C.G.	1·02	9·2
,, ,, ...	3 Ac	0·59	5·3
French wire	3 Ac	0·71	6·4

C.G. = Coal-gas. Ac = Acetylene.

Ballard and Harris in a recent paper also give results of oxygen contents for wire pistols which are particularly interesting (Table XV).

TABLE XV.—*Percentage of Oxygen in Copper Deposits (Ballard and Harris).*

Nozzle Distance, Inches.	Coal-gas Fuel (450 B.T.U.).		Acetylene Fuel Gas.		
	English.	French.	English.	French.	American.
1	0·79	0·35	0·32	0·33	...
2	0·80	0·40	0·56	0·46	0·74
3	0·90	0·54	0·54	0·65	0·90
4	1·10	0·60	0·61	0·76	1·03
5	1·15	0·69	0·69	0·75	1·12
6	1·08	0·66	0·66	0·72	1·04
7	0·95				1·06
8	0·91				1·27
9	0·75				

English pistol designed for coal-gas. French pistol designed for acetylene.

Ballard and Harris also studied the effect of spraying either continuously or intermittently on the oxide content of copper, their results being as follows :—

TABLE XVI.—*Effect of Intermittent Cooling on the Oxygen Content of Copper Coatings.*

Wire pistol, nozzle distance 3·5 ins.

Fuel Gas Used.	Method of Spraying.			
	Continuous.		Intermittent.	
	English.	French.	English.	French.
	Per cent.	Per cent.	Per cent.	Per cent.
Acetylene . . .	0·54	0·77	0·36	0·49
Coal-gas . . .	0·97	0·57	0·66	0·39

In continuous spraying on the same area of surface the coating is rapidly heated and it appears that greater oxidation occurs than when the coating is kept cool. This is not unexpected, since oxidation of the metal occurs (1) in melting, (2) during flight and (3) on the surface of the article. At close distances the particles are in a reducing zone of the flame, thereby being protected from oxidation in flight. To obtain deposits low in oxide, it would appear advisable to use a slightly reducing flame and to reduce the nozzle distance so far as it is possible without overheating the base. Unfortunately, a pistol using a reducing flame is not working at its maximum efficiency. In the above tests the English pistol was designed for use with coal-gas and gives greater oxidation than when using acetylene. Chilling of the article being sprayed has been partially successful in reducing oxidation of the coating.

In one German pistol carbon dioxide is used for atomising in the case of low melting point metals, and the use of nitrogen instead of air has also been suggested but not worked commercially. The following tests (Table XVII) show that the reduction in oxide by the use of nitrogen instead of compressed air would not justify the extra expense.

TABLE XVII.—*Oxygen Content of Sprayed Copper Coating, using Nitrogen (Ballard and Harris).*

Fuel Gas.	Type of Pistol.	Nozzle Distance.	
		1 inch.	3 inches.
		Per cent.	Per cent.
Acetylene	English . .	0·11	0·15
,,	French . . .	0·50	0·54
,,	American . .	0·61	0·64
Coal-gas	English . .	0·75	0·81
,,	French . . .	—	0·50

Compressed coal-gas and hydrogen do not produce stable flames when insufficient oxygen for complete combustion is supplied. Acetylene requires about 2½ times its own volume of oxygen for complete combustion, but it will burn with a stable flame with an equal volume of oxygen. Under normal conditions, 1 mm. diameter steel wire is sprayed with about 1¼ volumes of oxygen. When such a 1 : 1¼ mixture is used, the extra oxygen for complete combustion is taken from the atmosphere, which accounts for the secondary flame. For spraying steel, 0·4 cu. ft. of acetylene was used per minute, consuming about 0·45 cu. ft. of oxygen in the primary zone. About 12 cu. ft. of air per minute issued from the blast nozzle and this contained 2·3 cu. ft. of oxygen. Allowing a further 0·45 cu. ft. of oxygen for the secondary flame, the excess oxygen left in the blast is 1·8 cu. ft. per min. Fassbinder and Soulary and also Sillifant, therefore, experimented with the use of an inert atomising medium. Figs. 146 and 147 show the effects of using nitrogen when spraying 18/8 stainless steel. With high melting point metals a deposit is produced which is much freer from oxide films, but the usual laminated structure is still evident. Sillifant also used nitrogen to spray mild steel on to a 0·30 per cent. carbon steel bar and then annealed the sample at 900° C. Recrystallisation of the sprayed metal occurred, together with coalescence of the oxide films, and the carbon from the bar diffused into the coating. After such a treatment a ¾-inch diameter bar, 9 inches long, bearing a deposit $\frac{1}{16}$ in. on the diameter, could be bent cold through 90°.

Such a heat treatment, however, reduces the possible applications of metal spraying, because welding will give a sounder job with actual alloying at the weld junction and the distortion of a large article will be almost equal in each case.

FIG. 146.—Deposit of 18/8 Steel made under Normal Conditions. Appearance unetched, in a plane parallel to that of base.

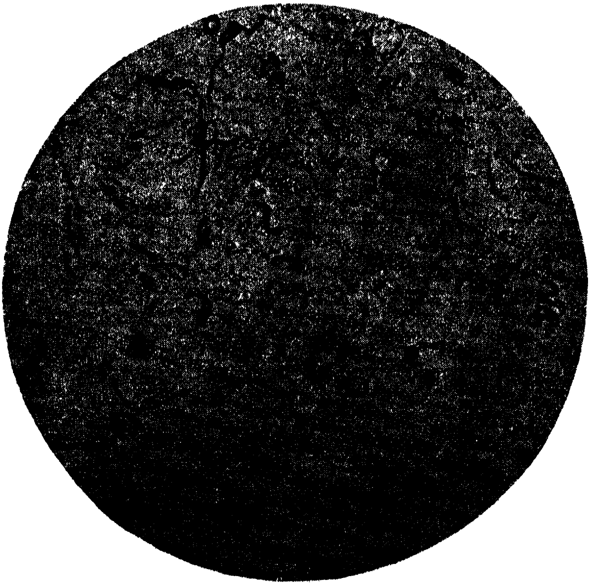


FIG. 147.—Same as Fig. 146 made with Nitrogen instead of Air.

The effect of oxygen pressure and air pressure on the oxide content of coatings was studied by Ballard and Harris with the following results :—

TABLE XVIII.—*Oxygen Pressure and Oxide in Coating* (*Copper*).

English wire pistol, using acetylene, at 3 inches nozzle distance.

Oxygen Pressure, lbs./in.^{2}	Oxygen, per cent. in Coating.
11	0·30
16	0·32
20	0·34
24	0·36
34	0·52

It is clear that increasing the oxygen pressure increases the oxide in the coating. The influence of air pressure was found to be comparatively small; in general there was a tendency for the oxide content of the coating to decrease as the air pressure increased. This effect may be due to the cooling effect of the air at the higher pressure. Thormann, however, assumed that there was greater oxidation with higher air pressure because he found that the hardness of the coating increased with increase of air pressure.

Steel, too, exhibits oxide inclusions, and it undergoes highly interesting modification on spraying. A portion of the carbon is burned off during the fusion and spraying process, thus preventing the oxidation which would otherwise have been somewhat extensive.

Owing to oxide, sprayed iron is harder than sprayed steel, but softening occurs during annealing owing to the coalescence of the oxide.

Effect of Carburising Sprayed Steel.—Sprayed steels are finding increasing use in building-up worn articles. Such steel has a hardness of about 200-250 Brinell and this is mainly due to the intimate admixture of the iron oxide in sprayed layers. Rollason has carried out a number of experiments on the pack carburising of sprayed mild and high carbon steels with the object of showing that such treatment does not have the normal effect. Fig. 148 shows the change in structure which occurs after this treatment. The heating causes the particles to sinter together and the porosity (black areas) is associated with the oxide masses (half tone) which are coalesced. The effect of the carburising material is to react with the oxide films near the edge of the specimen, resulting in almost oxide-free material. The Brinell hardness drops to a very low figure, normally 40-50, but this increases slightly when all the excess oxide is reduced to metal and pearlite begins to appear. This pearlite is always of an " abnormal " type, owing to the presence of oxygen dissolved in the steel.

Measurement of Porosity.—*Density Method.*—The porosity in sprayed coats, consisting as it does of isolated cavities and interconnected pores, is difficult to estimate absolutely, and no values are found in the literature. The interconnected pores allow liquids or gases to penetrate to the base metal, a disadvantage in certain applications, *e.g.* when copper is used to protect steel from carburising and also when the deposit is electropositive to the base. Recently Rollason has estimated the interconnected porosity (or permeability) by the following method. Built-up samples of sprayed metal ($\frac{1}{8}$-$\frac{3}{16}$ in. thick) were stripped from the base, weighed, boiled in toluene for 1 hr., and subsequently weighed suspended in toluene, the temperature being estimated to ± 0·1° C. The toluene penetrates the pores with great rapidity, and the specific gravity subsequently calculated is that of the metal, oxide, and isolated pores. The samples were then heated under reduced pressure until the original weight was obtained (in order to drive off the toluene).

The specimens were next coated with a very thin film of vaseline (0·02-0·04 gm.) and weighed suspended in distilled water. The film of grease prevented the water from penetrating the pores, and enabled consistent results to be obtained. The difference between the two calculated specific gravities has been converted to percentage (permeable) porosity as shown in Table XIX. The difference between the density (in toluene) and the density of the same metal in cast form indicates the extent of isolated pores together with oxides (Fig. 149). The results show that the powder process produces deposits with the greatest porosity, and this is undoubtedly due to the fact that the particles are cooler when they strike the base with the result that they are not closely interleaved. The English wire pistol using coal-gas produced zinc deposits with low " inter-connected " porosity, but the low density (in toluene) clearly indicates that there is an appreciable number of isolated pores. This is confirmed by reference to the microstructure shown in figs. 122 and 123. In many cases the oxides tend to fill up the pores.

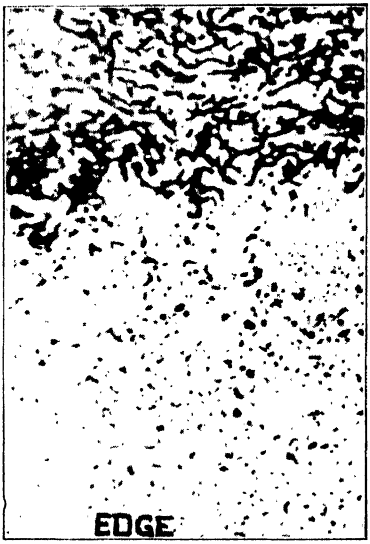


FIG. 148.—Microstructure of Sprayed Deposit after Pack Carburising.

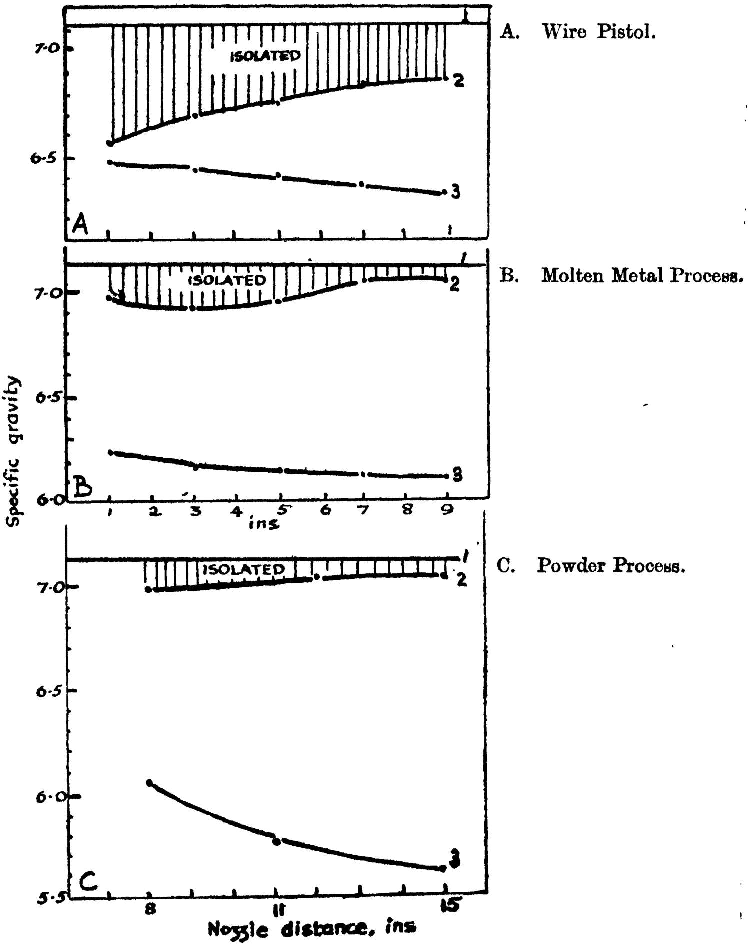
In these experiments the effect of variable nozzle distance from the base was studied. At very small nozzle distances the porosity is at its minimum, but it rapidly increases as the nozzle distance increases (fig. 150). This result is not unexpected since at close distances to the nozzle the

TABLE XIX.—*Porosity (Permeable) and Hardness of Sprayed Masses ($\frac{1}{8}$–$\frac{3}{16}$in. Thick). (Rollason).*

Process.	Metal.	Spraying Distance, Inches.	Specific Gravity.		Porosity, Per Cent.	Hardness.	
			In Water.	In Toluene.		Vickers (5 kg.).	Scratch 1/*W* (150 kg. Load).
English wire	Zinc C.G.	1	6·49	6·56	1.1	37·1	5·9
,, ,,	,,	3	6·44	6·71	3·9	29·9	5·4
,, ,,	,,	5	6·45	6·76	4·5	25	5·3
,, ,,	,,	7	6·37	6·85	6·6	25	5·3
,, ,,	,,	10	6·33	6·88	8·7	22	5·3
,, ,,	Zinc Ac	1	6·32	6·88	8·1	25·3	4·9
,, ,,	,,	3	6·36	6·84	7·0	26·2	4·9
,, ,,	,,	5	6·26	6·91	9·4	21·3	5·0
,, ,,	,,	7	6·29	6·96	9·5	22·6	5·3
,, ,,	,,	10	6·22	7·07	11·9	22	5·9
American (1)	Zinc Ac	3	6·15	6·76	8·9		
Molten metal	Zinc	1	6·24	6·98	10·6	35·5	6·0
,, ,,	,,	3	6·16	6·92	10·9	35·3	7·4
,, ,,	,,	5	6·15	6·96	11·7	34·3	7·7
,, ,,	,,	7	6·05	7·05	14·3	32·1	8·0
,, ,,	,,	9	6·04	7·04	14·4	34·3	6·7
,, ,,	,,	11	5·87	7·04	16·5	37·3	15·7
Powder	,,	8	6·04	7·00	13·8	28	5·1
,,	,,	12	5·76	7·06	18·4	19	5·3
,,	,,	15	5·63	7·05	20·1	21·6	5·9
American wire	Aluminium C.G.	N	2·35	2·69	12·8	30·7	
Powder	Aluminium	8	1·86	2·76	32·7	15·6	
,,	,,	11	1·81	2·76	34·3		
,,	,,	15	1·82	2·76	34·2	13·8	
Molten	Aluminium-Silicon	N	2·47	2·55	3·3	65	
,,	Tin	N	6·95	7·00	1·0		
English wire	Tin C.G.	1	6·85	7·08	3·3		
,, ,,	,,	3	6·59	7·07	6·8		
,, ,,	,,	5	6·53	7·03	7·0		
,, ,,	,,	7	6·53	7·09	7·9		
,, ,,	,,	9	6·51	7·12	8·6		
,, ,,	Copper C.G.	1	7·71	8·09	4·7		
,, ,,	,,	3	7·54	8·30	9·1	107	
Powder	Copper	8	6·27	7·98	21·4	66	
,,	,,	10	6·05	7·83	22·8	51·5	
,,	,,	12	6·13	7·84	21·8	5·5	
American wire	Copper	3	7·32	8·29	11·8	99	
English wire	18 : 8	N	6·50	6·92	6·1	264	
,, ,,	$0·7^{\circ}/_{0}$C Steel	N	6·33	6·55	3·4	236	
,, ,,	Mild Steel	N	6·44	6·59	2·3	309	
,, ,,	Lead	N	10·01	10·5	4·6		

C.G. = Using coal-gas. Ac = Using acetylene. N = Normal spraying distance.

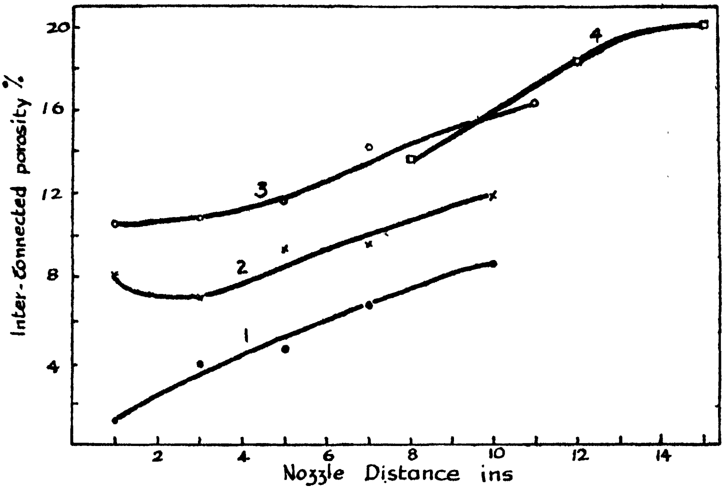
particles are sufficiently plastic to allow effective interleaving. At great nozzle distances the particles are cooler, more rigid, and have lower velocity, consequently forming a loose " heaped structure." Unfortunately, with the usual design of nozzle the difficulties of operating at close distance are great, due to overheating of the deposit and also to its unevenness.



Curve 1.—Specific gravity for sound zinc.
Curve 2.—Specific gravity of coating in toluene.
Curve 3.—Specific gravity of coating in water.

Fig. 149.—Effect of Spraying Distance on Specific Gravity of Deposits (Rollason).

Absorption Method.—Ballard and Harris have made measurements on the comparative porosity of sprayed coatings. Steel rod, ½ inch diameter, was mounted in a lathe, sprayed on the cylindrical face with ⅛ inch thickness of metal and left in the sprayed condition. Samples, 1 inch long, were weighed and immersed in refined paraffin for some days, with a vacuum maintained above the oil. After removal from the oil the samples were



Curve 1.—British wire-fed pistol, coal-gas.
Curve 2.—British wire-fed pistol, acetylene.
Curve 3.—Molten metal pistol.
Curve 4.—Powder pistol.

FIG. 150.—Effect of Spraying Distance on Porosity of Zinc (Rollason).

wiped dry with a clean rag and re-weighed. The increase in weight was due to absorbed oil and indicated the weight of oil which had penetrated into the interconnected pores. Typical results follow in Tables XX and XXI.

TABLE XX.—*Comparative Porosity for Wire Pistol Process—Weight of Oil Absorbed, gms.*

Nozzle Distance, Ins.	Using Coal-gas.		Using Acetylene.		
	English.	French.	English.	French.	American.
1	0·046	0·070	0·051	0·062	0·078
2	0·120	0·080	0·057	0·087	0·098
3	0·150	0·100	0·103	0·131	0·100
4	0·172	0·121	0·121	0·152	0·152
5	0·192	0·139	0·130	0·152	0·213
6	0·192	0·122	0·121	0·147	0·214
7	0·190	—	—	0·143	0·206
8	0·175	—	—	—	—
9	0·175	—	—	—	—

TABLE XXI.—*Comparative Porosity for Wire Pistol Process, using Nitrogen —Weight of Oil Absorbed, gms.*

Pistol.	Nozzle Distance.	
	1 in.	3 in.
English type using acetylene	0·042	0·082
French type using acetylene	0·055	0·162
American type using acetylene	0·097	0·136
English type using coal-gas	0·046	—

Transmission Method.—T. Everts * attempted to evaluate the porosity of sprayed metal coatings to air and water and the effect upon the porosity of various experimental conditions.

The coating was sprayed on to a circular polished iron surface. The deposit was then removed and fitted as a membrane inside a pipe. Water or air under an excess pressure of one atmosphere was supplied on one side of the membrane and the amount of the medium penetrating the coating in a known time was measured. The apparatus was very similar to that used by Schoop and described later in this section.

The soundness of the coating was expressed as the number of seconds taken by 1 litre of gas to penetrate 1 sq. cm. of the coating (0·5 mm. thick) under an excess pressure of 1 atmosphere at 15° C.

The various experimental conditions investigated for a wire pistol included:—(1) time of spraying, (2) distance of nozzle from surface, (3) hydrogen and oxygen pressures, (4) pressure of compressed air, (5) rate of feeding of metal wire. The metals which were investigated included zinc, aluminium, lead, monel metal, iron and V2A steel. The results are shown in fig. 151. The results given in fig. 151A show that the thickness of coating has little effect in the case of aluminium, but greatly decreases the permeability of V2A steel and lead to gases. The porosity of lead and aluminium coatings increases rapidly with increasing distance of the nozzle from the surface (10-30 cms.), but in the case of monel and iron deposits little effect was noticed and with a neutral flame the compactness of V2A steel improved (fig. 151B). Increasing the hydrogen pressure (1 to 2 atm.) decreased the porosity of all coatings, but the greatest effect was produced in the aluminium and lead coats (fig. 151C).

Excess oxygen in the flame increases the porosity in lead and zinc, decreases it in iron and copper and has little effect on aluminium coats (fig. 151D).

An increase in the air pressure had practically no effect on the porosity of aluminium, zinc and copper, but had a pronounced effect on lead and V2A coatings, the former becoming very porous (2·0-2·6 atm.) and the latter more compact (1·8-2·6 atm.) (fig. 151E).

In all cases an increase in the rate of feeding the wire tended to increase the porosity owing to the failure to liquefy the wire (fig. 151F).

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* *Z. Metallk.*, 1936, **28**, 143.

The optimum conditions for the production of sprayed coatings according to German practice using hydrogen are given in Table XXII, but these possibly vary when coal-gas is used.

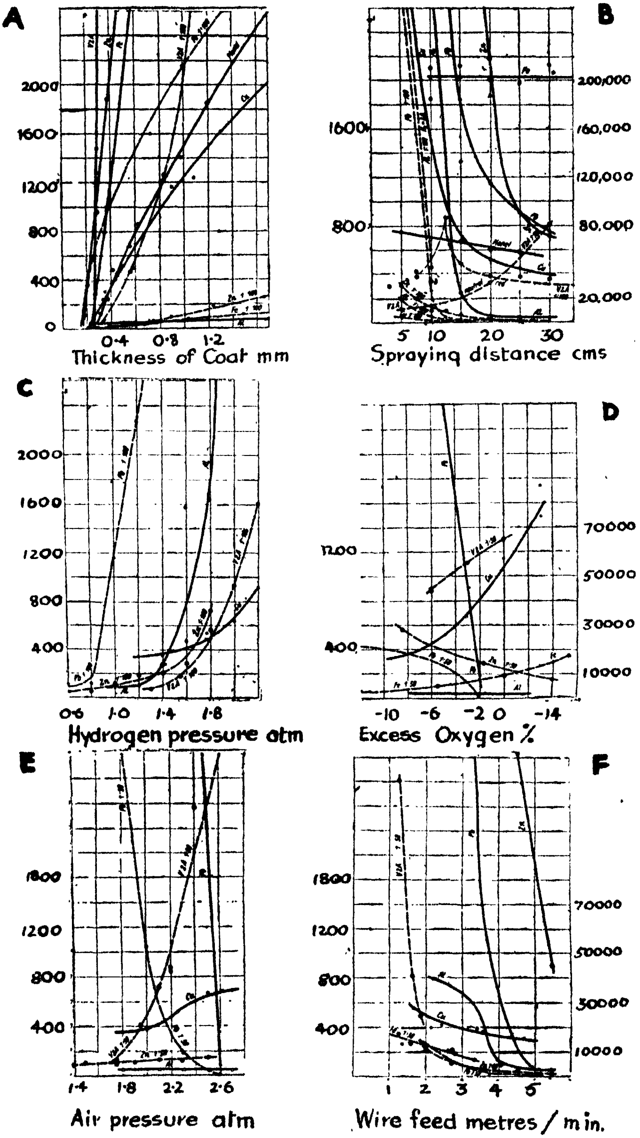

FIG. 151.—Effect of Spraying Conditions on the Permeability of Coatings Sprayed with Wire Pistol (Everts).

TABLE XXII.—*Conditions for Producing Sound Coatings (Everts).*

Metal.	Spraying Distance, Ins.	Hydrogen Pressure, Atm.	Oxygen Pressure, Atm.	Air Pressure, Atm.	Wire, Feed, Ft./min.	Improvement.
Copper .	4	2·4	2·4	2·7	12·2	13
Aluminium	2	2·4	2·3	2·7	18·3	6600
Zinc .	2	1·8	1·65	2·4	15·2	430
Lead .	2	1·6	1·5	2·0	13·4	330
V2A .	8	1·8	1·7	2·7	4·9	4
Steel .	8	1·8	1·9	2·2	3·7	8

The last column in Table XXII gives the improvement in soundness of the coatings as compared with that produced under ordinary conditions.

The effects of various after-treatments of the coatings are given in Table XXIII as average values.

TABLE XXIII.

Effect of Treatments on Soundness of Coating (-fold increase) (Everts).

Metal.	Heating.	Grinding.	Polishing.
Copper . .	11	19	137
Aluminium .	11	235	320
Zinc . . .	11	100	40
Lead . . .	—	610	270
V2A . . .	5	4·9	11
Steel . . .	3	5·4	800

Everts also attempted to estimate the number of pores in the coatings by direct counting under the microscope. The results are given in Table XXIV, which shows that copper and aluminium had comparatively few pores, but they were of large diameter; while zinc and lead had a much larger number of pores of smaller diameter.

TABLE XXIV.—*Type of Porosity.*

Metal.		Number of Pores per mm.^{2}	Size of Pores mm.
Copper . .	porous	22	0·002-0·007
Copper . .	dense	5	0·0025
Aluminium .	porous	22	0·002-0·02
Aluminium .	dense	45	0·0003-0·0007
Zinc . .	—	1000	0·0001-0·001
Lead . .	dense	5000	0·00001-0·0001
V2A . .	—	20	0·0005-0·001

In measuring the permeability of the coating to water it was found that the coating became impermeable after reaching a certain critical compactness, 160,000 and 90,000 sec./litre/cm.^{2} for aluminium and zinc respectively. Permeability to water also depends on the size of the pores and a thickness of over 0·2 mm. was required (1 atm. pressure).

Schoop used the apparatus shown in fig. 152 for estimating porosity. The most important part of the apparatus is, for clearness, shown separately in fig. 153. This apparatus permits a circular disc of the metal layer under examination to be arranged in an air-tight chamber so that, from one side, gas under pressure may act upon it.

In fig. 153, *a* is the disc of sprayed metal, *b* is a washer of rolled lead sheet. Disc and washer lie in a cavity of the metal body *c*, which is provided with the thread *d*. The union nut *e* is screwed on and presses with its annular internal shoulder against the metal disc to be tested until its edges are made air-tight. The side of the disc left free, which measures exactly one square centimetre, is set under gas pressure, for which purpose the nipples *f* and f_1 are used, and the gas passes through according to the porosity or solidity of the piece either slowly or rapidly. In order to be able to measure the quantity of gas, it is led by tubes into a pneumatic trough and there caught in a measuring cylinder. In fig. 152 the container *g* represents the pneumatic trough on to which the measuring cylinder *h* has been directly fused. At the side is fixed a spout *i* through which the water displaced from the measuring cylinder can run into a vessel below; by this arrangement the water in *g* is maintained at constant level. The gas tube *k* which leads to directly below the measuring cylinder is also

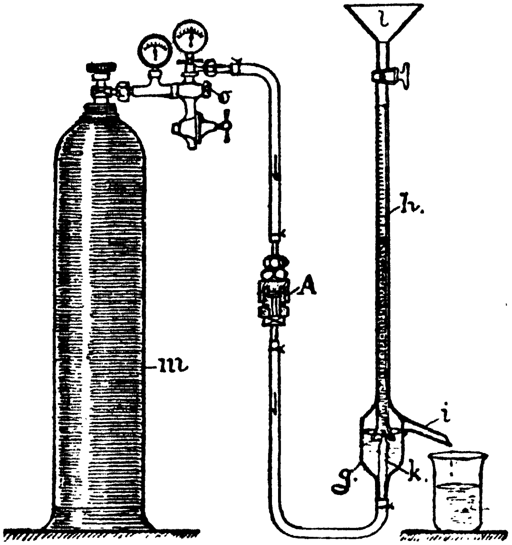

FIG. 152.—Apparatus for the Measurement of Porosity of Sprayed Coatings (Schoop).

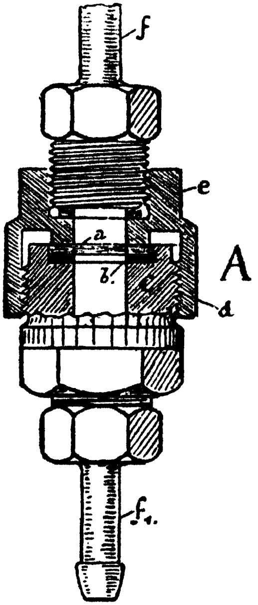

FIG. 153.—Enlarged View of A, fig. 152, showing detail.

fused on to the container *g*. The measuring cylinder is closed at the top by means of a tap, above which a filling funnel *l* is attached. A steel cylinder *m* delivering the hydrogen gas under pressure, and a reducing valve *o* complete the apparatus.

Method of Working.—When the metal disc to be examined has been fixed in position, the spout is closed with the finger, the tap opened, and the measuring cylinder *h* filled through the funnel with water *l*, the tap is now closed and the finger removed from *i*. By carefully opening the tap, water is run out until the upper end of the water column corresponds with the zero of the divisions. At this stage the disc is set under constant pressure such that the measuring cylinder is filled in a certain period of time with a sufficient quantity of gas. Then, knowing the time, temperature, and height of the barometer, the quantity of gas at normal pressure which passes through the disc in a unit of time may be calculated. Also, the water flowing from the spout *i* serves as a basis for determining the quantity of gas which has passed through the disc, provided care has been taken that no loss has occurred by evaporation.

Example.

Sprayed lead sheet 2 mm. thick.

Begun at	3·19.
Height of liquid column (or amount of gas)	8 c.c.
Finished at	5·19.
Height of liquid column (or amount of gas)	10·4 c.c.
Duration of experiment	2 hours.
Gas permeated through disc	2·4 c.c.
Gas pressure (hydrogen)	10 atmos.
Size of surface under pressure	·1 sq. cm.
Temperature at time of experiment	15° C.
Height of barometer	740 mm.

$$V_0 = \frac{273b}{273 - t760} = \frac{0{\cdot}923 \times 2{\cdot}4}{2} = 1{\cdot}29 \text{ c.c.}$$

Thus the quantity of gas (reduced to normal state of barometer and 0° C.) which passed through the disc in 1 hour at 10 atmospheres pressure amounted to 1·29 c.c.

With this porosity tester a great number of experiments have been carried out and show that the solidity of sprayed layers of the soft metals—for example, lead, tin, and zinc—is in general considerably greater than that of the harder metals—for example, copper, nickel, and silver. Naturally the result is influenced among other things by the thickness and surface structure of the metal plate to be examined, the fineness of the spray and the length of the spray cone, *i.e.* the distance of the pistol from the surface sprayed.

Vacuum Method.—The principle of another possible method to estimate porosity is illustrated in fig. 154. A standardised specimen is placed in a closely fitting chamber S and sealed up tightly. The chamber A is empty, but of known volume, preferably equal to the free space in S. Chamber S is connected to a vacuum pump P and is evacuated to a low known pressure.

The connection to the pump is then closed, the two chambers connected together, and the change in reading of the manometer noted. The porosity can be calculated from the following formula :—

$$S = V_A \frac{P_2}{P_1 - P_2} - (V_S - V)$$

where

S = pore volume.
V = volume of specimen.
V_S = volume of chamber S.
V_A = volume of chamber A.
P_2 = equilibrium manometer reading.
P_1 = evacuated manometer reading.

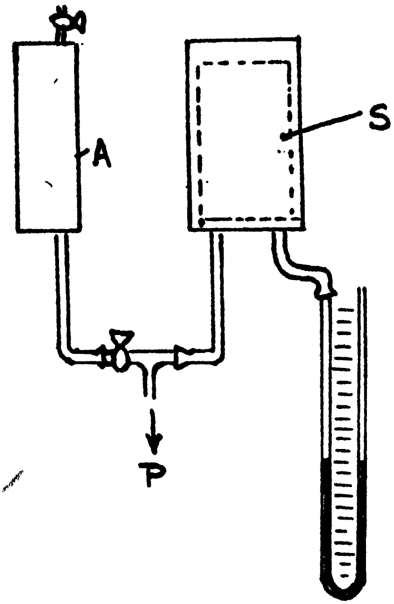

FIG. 154.—Vacuum Method of Estimating Porosity.

The accuracy can be checked by measuring the porosity of a solid piece of metal. Unfortunately the volume of the sprayed specimen has to be found by density measurements or by computation.

Bases of possible value for the consideration of the temperature and the degree of plasticity of the particles may be obtained by spraying well-cleaned plate glass held at right angles to the direction of the spray and upon which the projected metal forms a mirror. A mirror of this kind is clearer and cleaner the warmer and more metallic the particles when they strike. This experiment may also be used to assist in determining the size of the particles or the grade of spraying.

Now it is well known that numerous metals have the property of taking up hydrogen and other gases while in the molten state. This property is common to iron and to a greater extent to nickel and silver, the so-called "spitting" occurring by reason of the occluded gases being driven out on solidification. It is apparent that both the absorption of gases and also the "spitting" play a certain role in metal spraying, and may influence the solidity or porosity of the sprayed layer. This fact is not surprising in view of the great surface area of metal exposed to the surrounding gases; however, one must bear in mind that the fluidity of the molten metal has also an influence upon the results achieved.

The measurements of porosity have further shown that a subsequent mechanical or physical treatment of the specimen, such as annealing, hammering, rubbing, or polishing, often alters the result very materially and almost always in a favourable sense. By subsequent chemical treatment favourable changes may be effected, as already indicated.

Hopfelt speaks very highly of the quality of the coatings obtained with zinc in the spray rumbling barrels. Such coatings are, he asserts, quite non-porous as tested by the above method and very firmly adherent. In order to increase the solidity of sprayed coatings various measures may be employed, such as mechanical treatment, scratch brushing, rolling, hammering, and so on. But these operations can only be carried out on simple forms of articles.

Porosity may to some extent be overcome by spraying, either as an intermediate layer or as a top coating, such metals as fill up the pores of other coating metals. Thus, for example, brass, copper, and nickel coatings may be made solid by giving an intermediate or top layer of tin and by subsequent heating to 225° and 250° C. The tin melts, runs into and fills the pores of the metal layers above and below. If the tin is applied as a top coating it can be vigorously rubbed with a cloth or pad while in the molten condition, thus ensuring its penetration into the pores and cavities; it is well to use a little flux when doing this. Zinc forms a satisfactory underlayer, and this is especially to be recommended for cast-iron articles which are to be subsequently tinned by the immersion process. The zinc-sprayed articles are very readily covered with a beautifully smooth tin layer, which is very durable on account of its alloying with the zinc layer. The reverse process to this also gives very satisfactory results; thus, if an article straight from the galvanising bath be sprayed with tin a very firm alloy layer is formed. The process is suitable for the interior preparation of milk cans. The zinc is said to be rendered harmless from a toxic point of view by alloying with the tin layer.

Lead coatings have much to recommend them for the chemical factories, but must not be used too thin; they should preferably be ½ to 2 mm. thick.

For filling up cavities in iron, brass, copper, and aluminium vessels, thick coatings of aluminium are very satisfactory. In an iron vessel with walls 4 mm. thick, 5 holes 4 mm. in diameter were drilled, these holes were then filled up by spraying with zinc, brass, copper, iron, and aluminium. The vessel was then put under water pressure, and it was observed that the holes filled up with iron and aluminium were completely water-tight at 25 atmospheres pressure. The remaining metals did not, however, become sufficiently solid to maintain this pressure even after hammering.

Besides the improvement in density and decrease of porosity induced by pressing, hammering, rolling, and polishing the coatings, there is the improved appearance to be considered, especially that produced by polishing.

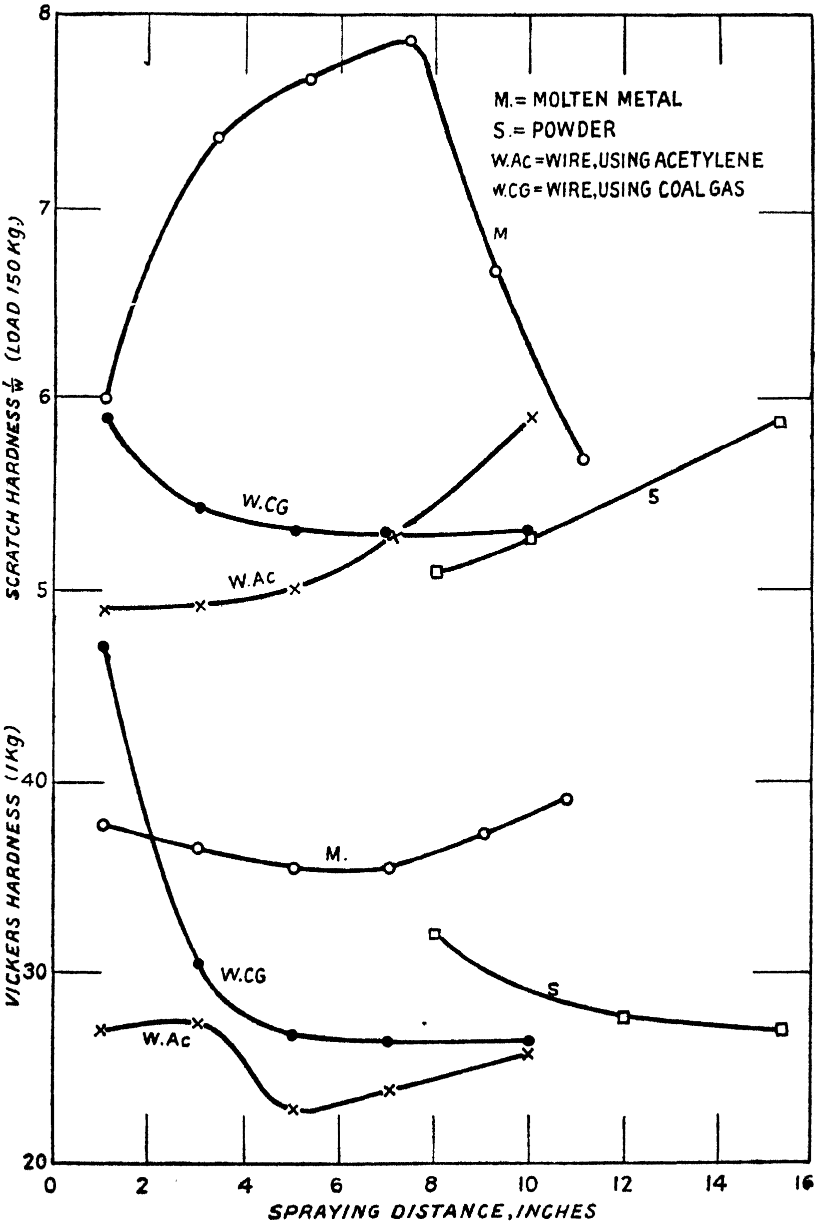

FIG. 155.—Effect of Spraying Distance on the Scratch and Vickers Hardness of Sprayed Zinc (Rollason).

For some purposes in its raw state the sprayed metal coating is useless because of the matte finish due to the necessary roughening of the old surface with the sand blast. Polishing sprayed metals is more difficult and expensive than polishing electro-plated goods, because the former are initially rougher, and being built up of interlocking particles, some of those from the upper layer are liable to be pulled off during the operation. This risk is not so great in the case of cross or longitudinal sections, by reason of the interlocking of the particles. Where polishing has to be done, the roughness of the unpolished surface necessitates the deposition of a thicker coating than suffices with other processes, which adversely affects the economic value of spraying for such purposes. Violent polishing of sprayed, or indeed any type of coatings, may loosen them from their foundation and thereby give the trouble of renewing part or even the whole coating.

Hardness of Sprayed Metals.—Sprayed metals and alloys do not possess the same hardness values as cast or wrought metals. Both Turner and Rollason have carried out hardness tests both upon sprayed coatings and upon solid blocks of material built up by spraying. These tests were carried out in the Metallurgical Department of the University of Birmingham upon metals and alloys sprayed in England under normal working conditions.

The hardness of sprayed deposits is becoming more important owing to the increased use of the process in the building up of worn articles. It is greatly affected by the amount of oxide and porosity of the coat, because a material full of pores has less resistance to penetration than sound metal, consequently yielding a lower Brinell number. On the other hand, oxide particles in the same material will tend to give a high scratch hardness. In mild steel the oxide present as sprayed makes the material almost unmachinable, but annealing decreases the hardness due to agglomeration of the oxide. A few hardness values are given in Table XIX and in fig. 155, which shows the effect of nozzle distance on both the Vickers hardness and the scratch hardness of coatings produced by the wire, powder and molten metal processes. Hardness figures obtained with the same apparatus on cast materials are given in the following tables for comparison. In the diamond-scratch hardness tests the weight upon the diamond point was 50 grams in each case. The ball hardness figures were obtained with a steady load of 10 kilograms on a 1-millimetre ball for 20 seconds.

TABLE XXV.—*Scratch Hardness Tests** (*Wire Pistol*)—*Turner.*

Metal or Alloy.	Cast Material.	Sprayed Coating.	Sprayed Lump Tested on Top.	Sprayed Lump Tested on Side.
Tin . .	0·08	0·056	0·055	0·055
Aluminium .	0·06	0·044	0·048	0·05
Zinc . .	0·05	0·032	0·033	0·035
Copper .	0·05	0·029	0·03	0·03
Iron . .	0·02	...	0·02	0·022
Brass .	0·05	0·032	...	...
Bronze .	0·023	0·025	...	...

* The figures given are the widths of the scratches measured in mm.

TABLE XXVI.—*Ball Hardness Tests* (Wire Process)—Turner.*

Metal or Alloy.	Cast Material.	Sprayed Coating.	Sprayed Lump Tested on Top.	Sprayed Lump Tested on Side.
Tin	>0·8	0·77	0·8	0·8
Aluminium	0·61	0·44	0·57	0·62
Zinc	0·44	0·42	0·55	0·57
Copper	0·54	0·38	0·42	0·54
Iron	0·32	...	0·33	0·38
Brass	0·54	0·43	...	...
Bronze	0·3	0·43	...	...

TABLE XXVII.—*Scleroscope Hardness Figures † (Wire Process)—Turner.*

Metal or Alloy.	Cast Material.	Sprayed Block Tested on Top.	Sprayed Block Tested on Side.
Tin	5-6	11·5	11·0
Aluminium	6	12·0	10·0
Zinc	12	19·0	13·0
Copper	17	50·0	47·0
Iron	25	55·0	45·0

From Tables XXV, XXVI, and XXVII, it may be seen that, tested by scratch or by scleroscope, the sprayed metal is decidedly harder than similar metal when cast. However, when tested by the ball indentation method, there seems little difference between the two, but if anything the sprayed metal is in some cases slightly softer than the cast.

Hardness tests made some years earlier by Arnold with the Martens-Heyn ball tester indicated that, except in the case of tin and steel, the hardness was lowered by spraying.

The brittleness noted in sprayed metals is attributable to the fact that the sprayed metal body consists, not of welded or fused, but of matted and interlocked particles which may be separated more readily than can the adjacent grains in a cast material.

The presence of cavities as indicated by the density determinations would influence any hardness tests, so that the individual particles of metal may well be harder than cast material, though the steel ball of the tester is able to compress the whole mass of metal more easily in consequence of these cavities. The circumstance that steel becomes harder on spraying is due, as shown by fig. 157, to the accompanying modification of the structure from that shown in fig. 156, that is, owing to the oxide inclusions.

This change after spraying the steel wire is due to a portion of the carbon having been burned off during the melting and spraying process, incidentally preventing the oxidation which might otherwise have been extensive. It is evident also, that the transformation of pearlite into a fine state, together

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* The figures given are the measured diameter of the indentation in mm.

† The figures given were all obtained with the same instrument and the same magnifier hammer.

with the iron oxide, must naturally be accompanied by a considerable hardening of the sprayed metal particles.

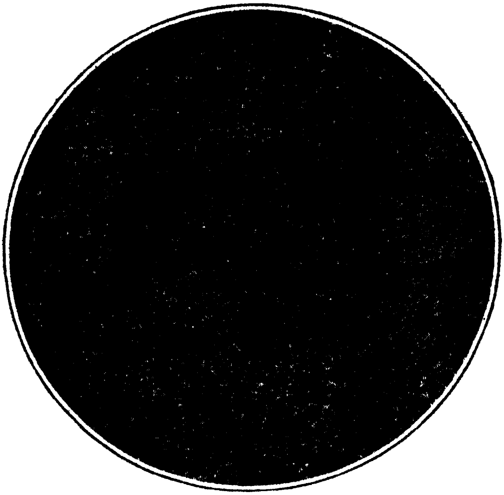


FIG. 156.—Silver Steel as supplied ; Granular Pearlite (Arnold).
Magnification not given.

FIG. 157.—Silver Steel, Sprayed (Arnold).
Magnification not given.

Both Thormann and Everts have studied the effect of spraying conditions, using a wire pistol, on the hardness of the coating produced. The main conclusions of Thormann are expressed in fig. 158.

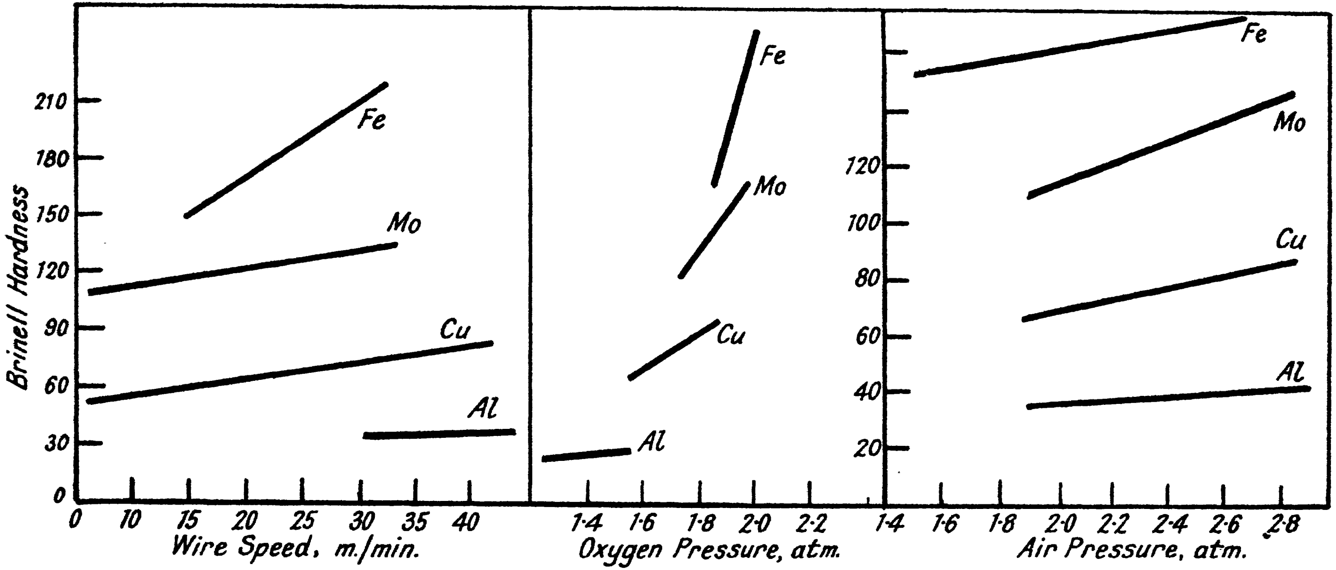


Fig. 158.—Effect of Spraying Conditions on Hardness of Deposits (Thormann).

(*a*) *Temperature of Base.*—If the temperature of the object is increased up to a temperature of 200° C., the Brinell hardness of the coating falls, except in the case of zinc, in which the hardness increases due to the oxide content.

(*b*) *Wire Feed.*—Increase in speed of wire feed produces an increase in Brinell hardness, but the slowest speed produces the highest scratch hardness in the case of zinc and V2A steel.

(*c*) *Oxygen Pressure.*—The hardness increases with increasing oxygen pressure, owing to the increased oxide content in the coating.

(*d*) *Hydrogen Pressure.*—With increased hydrogen pressure a hotter flame is formed which, in turn, produces a hard coating. Near to the pistol the particles will be in a reducing atmosphere and a lustrous coating will be produced.

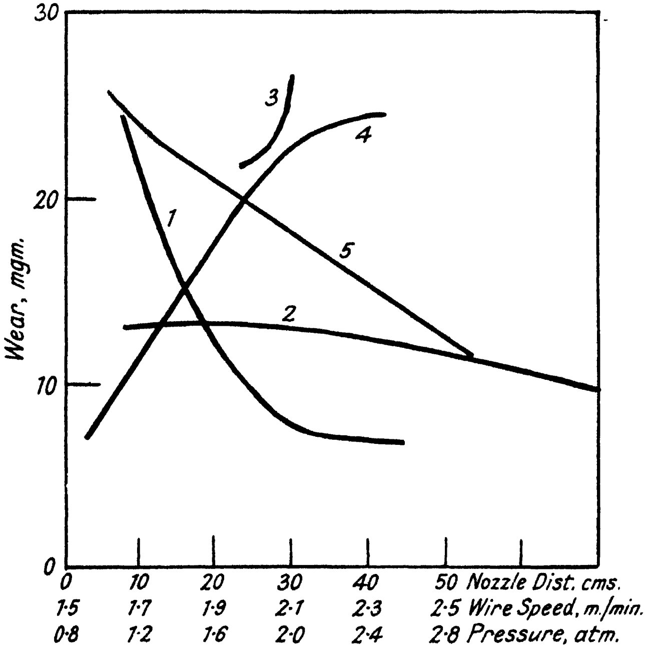
(*e*) *Air Pressure.*—With high air pressure the oxide content of the coating is increased owing to the strong disturbance of the jet and the particles are

TABLE XXVIII.—*Brinell Hardness of Sprayed Metals* (*Fassbinder and Soulary*).

Metal.	Pistol. P = Powder W = Wire.	Fuel. Ac = Acetylene C.G = Coal-gas.	Projecting Gas.		Nozzle Distance, cms.	Pistol. M = Moved F = Fixed.	Brinell Number.	Hardness of Casting.
			Air or Nitrogen.	Pressure, kg./cm.^{2}				
Zn	W	Ac	Air	4	18	M	23	24
Zn	W	Ac	Air	4	18	M	23·5	24
Zn	P	Ac	Air	4	18	M	17·5	24
Zn	W	Ac	N	4	18	M	19	24
Zn	W	Ac	N	4	5	M	18	24
Al	W	Ac	Air	4	18	M	35	21
Al	W	Ac	N	4	18	M	35	21
Al	W	Ac	Air	2·5	18	M	28	21
Al	W	Ac	N	2·5	18	M	32	21
Al	W	Ac	Air	4	5	M	40	21
Al	W	Ac	N	4	5	M	36	21
Al	W	Ac	Air	2·5	5	M	26	21
Al	W	Ac	N	2·5	5	M	30·5	21
Cu	W	Ac	Air	4	18	M	84·5	50
Cu	W	Ac	N	4	18	M	90	50
Cu	W	Ac	Air	4	18	F	91	50
Cu	W	Ac	Air	4	18	F	61·5	50
Cu	W	C.G.	N	4	18	F	76·5	50
Cu	W	Ac	N	4	18	F	97	50
Brass 70/30	W	Ac	Air	4	18	M	103	58
	W	Ac	N	4	18	M	58	58
Mild Steel	W	Ac	Air	4	18	M	199	118
	W	Ac	N	4	18	M	168	118
	W	C.G.	N	4	18	F	226	118
Rustless 18/8	W	Ac	Air	4	18	M	187	160
	W	Ac	N	4	18	M	106	160
	W	Ac	N	4	18	F	96	160

hammered tightly into position. For these reasons both the scratch and Brinell hardnesses increase.

Fassbinder and Soulary also made Brinell hardness tests, the results of which are given in Table XXVIII. The coatings made with nitrogen showed lower hardness values than those made with compressed air as the atomising agent in cases where the sprayed metal had a high melting point. On the other hand, the substitution of nitrogen for compressed air had practically no influence on the hardness of the deposits made with soft metals. In the case of hard metals (steels) the variation in hardness between the top and the bottom face in contact with the article may reach 20 per cent.



Curve 1.—Nozzle Distance.
Curve 2.—Wire Speed.
Curve 3.—Oxygen Pressure.
Curve 4.—Hydrogen pressure.
Curve 5.—Air pressure.

FIG. 159.—Effect of Spraying Conditions on Wear Resistance of Deposits (Thormann).

Resistance to Wear.—The effect of spraying conditions, using a wire pistol, on the resistance to wear was studied by Thormann using a machine designed by Schmidt. A rectangular piece of sprayed metal was passed, under pressure, over a plate of wear-resisting cast iron and the loss in weight after passing for a distance of 2,400 metres served as a measure of wear. The results obtained are given in fig. 159. The wear increased when the base was heated, owing to the drossy porous structure produced, but decreased with increasing nozzle distance. Wear also increased if the oxygen or hydrogen pressure was increased, owing to the increase in oxide content. On the other hand, wear decreased with higher air pressure owing to the better interleaving of the particles, and also decreased with increase of wire speed.

Unfortunately, these tests, under German practice, showed that even if steel is sprayed under the most favourable conditions, the resistance to wear achieved falls far short of that of cast material.

While metal spraying has been applied unhesitatingly for the building-up of worn journals or shafts for slow-running parts or on parts of minor importance, some doubt is still felt when the building-up of major journals, such as internal combustion engine crankshafts, is considered. Certain concerns are building-up crankshafts regularly by metal spraying, but no large-scale work is being done on these lines, as, say, the building-up of all worn crankshafts of a large fleet of buses.

It is still felt, even by those who are firm believers in the process, that considerable doubt remains as to the reliability of metal-sprayed surfaces for such major purposes. With the object of finding the truth of the matter, H. Shaw conducted an investigation into the use of metal-sprayed surfaces.

In the first place, the investigation was carried out on actual crankshafts. In all, tests were made on some 22 engines, of which five were private car engines, four commercial vehicle engines, five petrol bus engines, and eight Diesel bus engines. The crankshafts were reduced on half the journals to about $\frac{1}{8}$ inch below normal diameter, built up by metal spraying with steel, and finished to size, this giving a sprayed-metal thickness of about $\frac{1}{16}$ inch. One crankshaft from each class of engine was given a thickness of sprayed-metal of only $\frac{1}{32}$ inch. Checks of the wear on the metal-sprayed journals and on the ordinary journals were made over running distances of 1,000, 5,000, 10,000 and 15,000 miles, and in no case did the wear on the sprayed journals exceed that on the ordinary journals. The difference in the thickness of metal spraying of $\frac{1}{32}$ inch to $\frac{1}{16}$ inch appeared to have no influence on wear.

On the private car engines, commercial vehicle engines and petrol bus engines the wear on the metal-sprayed journals was, on an average, 15 per cent. less than that on the ordinary journals, the vehicles used for the greatest stop and start work showing up the metal-sprayed surfaces to greatest advantage. In the Diesel bus engines the wear on the metal-sprayed journals was but 50 per cent. of that on the plain journals.

The most remarkable effect of the metal-sprayed journals was that the wear on the contacting bearings was much less than on those contacting with the plain journals. The wear was 40 per cent. less on the average and 55 per cent. less in the Diesel engines. To find, if possible, a reason for this, tests were made using hardened steel surfaces, ordinary soft steel surfaces and metal-sprayed surfaces running against white metal surfaces to find the load at which seizure would take place. At a rubbing speed of 450 ft. per min., seizure of the white metal in contact with the hardened steel or soft steel took place at different loads ranging from 650 lb. to 750 lb. per sq. in., but with the sprayed steel surface seizure took place only at loads between 2,540 lb. and 2,750 lb., or at four times the previous load. The friction figures obtained during one of the tests of the sprayed steel in contact with the white metal are given in Table XXIX.

TABLE XXIX.

The Coefficient of Friction of Sprayed Steel running against White Metal at 450 ft. per min.

Load, lb. per sq. in.	Coefficient.
350	0·0402
450	0·0067*
650	0·0104
750	0·0125
1000	0·0182
1250	0·0176
1600	0·0166
1750	0·0159
2000	0·0148

The porous surface of sprayed metal has admirable oil-holding capacities, rather similar to porous oil-impregnated bearings, but the porosity does not greatly reduce the effective bearing area. There is no doubt that this porous nature of the metal-sprayed surfaces gives them their great load-bearing capacities and freedom from wear. This being so, it is to be expected that such surfaces would show up to particular advantage under conditions of partial film or boundary conditions. Tests were also carried out in which the time of running to produce seizure was measured after the oil supply had been cut off. The hardened steel shaft seized in 3 hours, but the sprayed steel shaft ran for 22½ hours (one shaft ran for over 190 hours when graphited oil was used).

In measuring wear after short periods it was found that this was slightly greater on the sprayed surfaces than on the hardened steel, but after continued running the relation was reversed.

Dilatation.—The dilatation behaviour of a sprayed deposit is important in certain applications where heat is applied. A few curves showing the effect of annealing are given in Fig. 160, as obtained by Rollason using a Gale-type dilatometer. The duration of the heating has an important influence on the results, and in these experiments the time taken to reach 1000° C. was approximately 1¼ hours.

Copper: On the first heating normal expansion occurs up to about 600° C., followed by a gradual contraction as recrystallisation occurs, together with coalescence of the oxide particles. During the second heating the contraction above 600° C. counterbalances the normal expansion, but a third heating gives normal expansion up to 1000° C.

Steel: The first heating curve is similar to that of copper, except for a small modification at 700° C. due to the effects of the volume changes associated with the critical ranges in steel. These latter volume changes become normal after the second heating.

Aluminium: Whilst the other materials exhibit a permanent contraction after heating, aluminium expanded about 1 per cent.

The contraction resulting from heating causes little trouble when the

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* This would appear to be a critical point.

coating is on a shaft, but tends to strip a lining from a hollow cylinder. The contraction is not uniform in all directions but is greater in a direction normal to the surface.

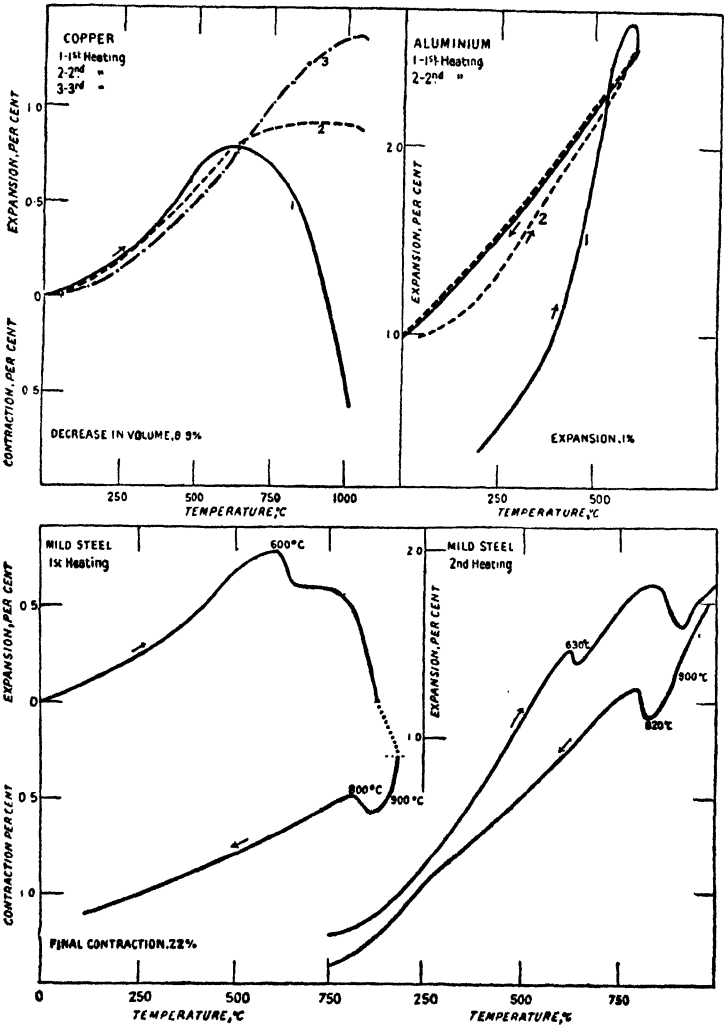
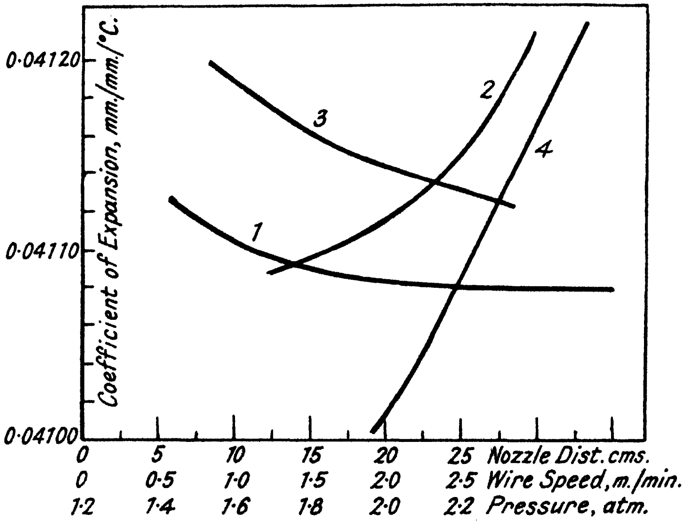


Fig. 160.—Dilatation Curves of Copper, Aluminium, and Mild Steel, sprayed by Wire Pistol (Rollason).

Thörmann has also determined the coefficient of expansion of metal sprayed by the wire process using hydrogen as fuel gas. The effects of spraying conditions are shown in fig. 161. Increasing the nozzle distance from 10 to 30 cm. caused a decrease of 2 per cent. in expansion, and an increase in hydrogen pressure also decreased expansion some 5 per cent. An accelerated wire feed reduced the oxide content and the sprayed metal became denser, with increased expansion. Increase in air pressure exercised a marked influence on the expansion due to the reduction in number of pores. Expansion increased 19 per cent. when the air pressure was raised from 2·0 to 2·6 atm.

Choice of Metal and Corrosion of Coatings.

Extensive researches which have been devoted to the elucidation of the causes of corrosion have now fairly well established the main facts that the actual attack is electrochemical in character and the various hypotheses differ mainly as to the factors by which the electrolytic action is brought about. The presence of moisture is a vital factor and oxygen also plays an extremely important part in the process. Very pure water can attack iron or steel in the presence of oxygen, but the corrosion is slow and usually tends to stifle itself owing to the low solubility of the oxides of iron which are formed on the surface. With a salt solution (such as sodium chloride) and an electric current, generated by methods to be discussed later, the corrosion can be greatly accelerated.



Curve 1.—Effect of nozzle distance. Curve 2.—Effect of wire speed.
Curve 3.—Effect of hydrogen pressure. Curve 4.—Effect of air pressure.

FIG. 161.—Effect of Spraying Conditions on Expansion of Sprayed Coatings (Thormann).

Electrode Potentials.—The theory of electromotive force is discussed fully in text-books on physical chemistry and only a brief outline is given here of the way in which an electrolytic cell is set up. When a salt, such as zinc sulphate, is dissolved in water it splits up partially—dissociates—into zinc particles having a positive charge and sulphate particles negatively charged, thus:

$$ZnSO_4 \rightarrow Zn^{++} + SO_4^{--}.$$

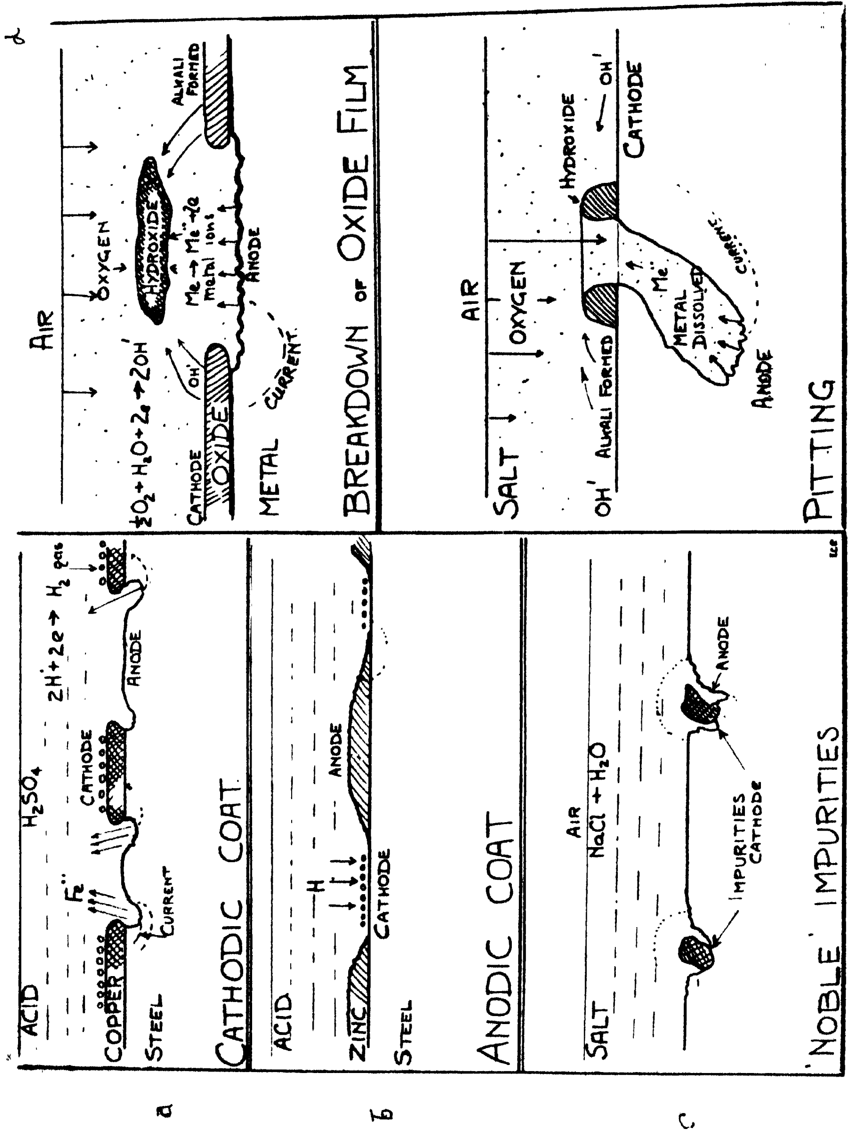
In this case two units of charge (electrons) are involved, and the charged particles are given the name of *ions*. If we immerse a piece of zinc in such a solution of zinc sulphate, containing a definite concentration of ions, we find that there is only one electric potential (voltage) at which equilibrium can exist between the metal and the solution. If a suitable scale is chosen the potential can be expressed in volts, as is frequently done by connecting the zinc electrode to a "hydrogen" electrode consisting of blackened platinum immersed in a certain concentration of hydrogen ions; its potential being taken as zero. In this way metals can be arranged in the following order according to their potentials giving a list known as the *electrochemical series*.

TABLE XXX.—*Electrochemical Series and Values of Overvoltage.*

Metal.	Electrode Potential. (volts)	Hydrogen overvoltage. (volts)
Platinum . .	+ 0·86	0·01
Silver . . .	+ 0·80	0·1
Copper . . .	+ 0·35	0·25
Hydrogen . .	0·00	
Lead . . .	— 0·13	0·6
Tin	— 0·15	0·5
Nickel . . .	— 0·20	0·15
Iron (ferrous) . .	— 0·34	
Cadmium . . .	— 0·42	0·5
Zinc . . .	— 0·77	0·7
Aluminium . .	— 1·34	
Magnesium . .	— 1·80	
Sodium . . .	— 2·72	

The ability of metals to resist corrosion is largely dependent upon their position in the electrochemical series. On account of their proximity to hydrogen, nickel and copper can be used in sulphuric acid, which may be regarded as a salt of hydrogen. The farther two metals are separated from one another in this series the more powerful is the electric current produced by their contact in the presence of an electrolyte (*i.e.* a solution having good electrical conductivity). Also the more rapidly the lower metal is attacked the more will the higher metal be protected. It must be remembered, however, that the order in the above series may vary slightly under special corrosive conditions.

Attack by Acids.—An example of a short-circuited cell is provided by an imperfect coating of copper on iron immersed in dilute sulphuric acid, shown diagrammatically in fig. 162. The current generated flows through the closed circuit; the iron dissolves and is called the *anode*; whilst the copper is known as the *cathode*. In such acid attack the hydrogen, which is freed as the iron dissolves, is deposited on the surface of the cathode and as it increases in amount two things may occur. The corrosion of the iron is either brought to a standstill because of the formation of a hydrogen electrode yielding a much lower voltage, *i.e.* the cell is *polarised*; or the hydrogen may be evolved as bubbles which stream away, with the result that the corrosion will occur continuously. In the first case the corrosion can be accelerated by the use of oxidising agents (*e.g.* air) which remove the hydrogen from the cathode.



Thus metals used for coating iron can be divided into two classes.

1. Metals like nickel or copper, having a positive potential towards iron, protect *mechanically*, by excluding corrosive influences. If the coating is

porous, attack occurs, which is occasionally more intense than that on bare steel. This accelerated attack only takes place if the potential between the metals is high and the liquid a good conductor.

2. Metals such as zinc or aluminium having a negative potential towards iron, are attacked preferentially to the ferrous base and can sometimes give electrochemical protection of the iron exposed at a gap, provided that the covering is attacked sufficiently rapidly to give the necessary current density. The iron remains bright until the exposed area is so large that the central portion is beyond the protective zone. This is an example of *sacrificial* protection. (Fig. 162*b*).

This effect depends on the electrolyte ; thus, for a crack of a given size, aluminium may protect steel against salt water but not against hard water, which fails to produce sufficient attack on the aluminium to generate the protective current on the steel. A zinc coating will protect against both liquids, being attacked more quickly in the salt water it is attacked with unnecessary rapidity, and will not last so long as an aluminium coat.

In the choice of coatings the properties of the various metals must therefore be carefully compared and considered. The same mechanism of corrosion is also involved in the corrosion of sheets of commercial metal containing impurities which set up local cells, as illustrated fig. 162*c*. A requirement of good resistance to corrosion is *structural* and *chemical uniformity* of the material. A second constituent or impurity only increases the rate of corrosion if it has a smaller *hydrogen overvoltage* than has the parent metal. Thus the corrosion of zinc is increased by additions of platinum, nickel, copper, cobalt, gold, antimony, silver and bismuth, in decreasing order of activity ; whereas thallium, cadmium, tin, lead and mercury have no effect owing to their high overvoltage (see Table XXX).

By overvoltage we mean the difference in potential between that required to produce gaseous hydrogen on a rough platinum surface and the more negative value on any other metal, the surface of which has an important influence.

Unless the initial voltage of the cell is greater than the overvoltage, all action will eventually cease. With zinc and copper the voltage of the cell is $0{\cdot}35 - (-0{\cdot}77) = 1{\cdot}12$; and the overvoltage of the copper is 0·25 volts ; the reaction proceeds. On the other hand, the voltage of a cadmium-zinc cell is only about 0·35 volts and the overvoltage of cadmium is 0·5 ; hence the reaction ceases.

The attack by acids, which has been discussed, depends on the *strength* of the acids (hydrogen ion concentration). Where very subtle differences in degree of acidity have to be mentioned it becomes troublesome to refer to hydrogen ion concentrations such as $\frac{N}{1,000,000}$, and it is more convenient to write them as 10^{-6} N and even abbreviate to 6, which is called the *p*H-value. Most acids also exhibit increased attack when *movement* occurs and when *oxygen* is present, except where passive or inert films are produced on the surface of the metal by oxygen and oxidising acids, such as nitric acid. For this reason mild steel is not attacked by concentrated acid but is rapidly dissolved in the dilute acid. Other very reactive metals such as chromium and aluminium can also be rendered passive by certain oxidising agents.

Effect of Oxide Films.—The passive nature of the metals just mentioned is now considered due to the formation on the surface of oxide films which protect the underlying metal from the action of corrosive media. Immunity depends upon the properties of the film such as:

(*a*) Thickness and impermeability to media.
(*b*) Adherence to the base metal.
(*c*) Resistance to chemical attack.
(*d*) Mechanical strength.
(*e*) The ability to repair defects which may arise in the film.

Such oxide films are produced even on exposure to air, and, although invisible while in contact with the base metal, have been separated and studied. The film produced on iron in many environments does not fulfil the above conditions, consequently corrosion occurs. Chloride and sulphate ions are especially liable to cause film breakdown, but chromates and phosphates promote repair. On the other hand, aluminium and chromium form films of the impervious type and this property is usually conferred on their alloys, so long as reducing conditions do not prevail. This dependence for resistance on the presence of oxygen is well illustrated by the corrosion rates of monel metal and stainless 18/8 steel in 3 per cent. sulphuric acid.

A tank made of 18/8 alloy would be immune from attack if the dilute sulphuric acid was aerated, but stagnant reducing conditions may set up attack at the bottom.

In acid solutions oxide films may dissolve or be reduced to a soluble oxide by the hydrogen formed in the pores.

Attack by Natural Waters.—Aerated salt solutions usually attack metal surfaces at the weakest points in the oxide film, such as scratches, cut edges and points of high strain. Once attack has commenced, undermining and consequent flaking off of the primary oxide causes the attack to spread out from the initial points of attack, with the exception of small weak points which often heal up owing to the precipitation of corrosion products *in situ.* The exposed parts of the metal become anodic towards the parts still covered with an oxide film and current flows between them. Hydroxyl ions (OH^-) are formed near the oxide film and, if sufficient concentration is produced, they will keep it in good repair. Diffusion of the hydroxyl and metal ions occurs and when they meet a precipitate of hydroxide is formed *away* from the seat of attack. This corrosion product does not therefore stifle corrosion, and the anodic areas spread and the cathodic diminish until a certain current density is reached, called "minimum protective cathodic current density" (see fig. 162*d*).

As a general rule the presence of oxygen is necessary for the continuance of corrosion of metals in neutral salt solutions. Natural waters are usually saturated with air, but the supply of oxygen may vary according to the depth below the surface of the solution. Evans has shown that such variations in oxygen concentration set up electrolytic cells, producing a current between two portions of the same metal to which oxygen is supplied at two different rates. The portion supplied with the smallest quantity of oxygen becomes the anode and is dissolved, while at the aerated part is formed a film with some protective properties. This mechanism explains both "pitting" and the attack of plates immersed vertically in salt solutions.

Pitting.—Cavities in a metal surface are particularly inaccessible to oxygen and therefore become anodic to the surrounding metal to which atmospheric oxygen can diffuse. This effect is illustrated in fig. 162*e*. The zinc chloride formed at the bottom of the cavity migrates upwards and reacts with the sodium hydroxide to form zinc hydroxide at the mouth of the crevice. This position of the corrosion product accentuates the corrosion by making the diffusion of oxygen to the anode more difficult and if the cathodic area is large severe pitting may occur. On the other hand, if the initial corrosion products are insoluble and formed in contact with the anode, attack is retarded.

Waterline Corrosion.—This type of corrosion is due to several causes, two of which are: (*a*) in metal prone to local attack, the waterline is a weak place; (*b*) metals such as zinc, tin, lead and aluminium which are soluble in alkali may suffer waterline attack because alkali is produced so readily in that zone.

Atmospheric Attack.—Corrosion products formed by the atmosphere are more or less adherent and the rate of attack depends largely on their nature, especially their hygroscopic properties. Some surfaces appear wet when there is no visible moisture in the air, that is at humidities below the saturation point. It appears that materials have critical humidities, such as 85 per cent. for nickel and 65 per cent. for iron corrosion products, above which attack occurs at a destructive rate.

Chlorine compounds are important near the coast, and so are sulphur compounds in industrial areas. Solid particles help to form fog which produces concentration cells when deposited on the metal. The washing effects of rain have an influence in removing such dirt and also corrosion products.

*Corrosion in Soils.**—The attack changes from one soil to another; marshy soils have high acid concentrations, while loose well-drained soils have low acidity. Dry soils frequently exhibit alkaline reactions, but have low rates of corrosion owing to lack of moisture. Pitting may occur due to concentration cells caused by the shielding effects of masses of soil and electrochemical attack may arise where the metal is situated in two different soils.

Metallic Protection of Steel.—The characteristics of a few metals commonly used for protecting iron and steel will now be discussed in brief outline.†

Zinc.—The use of zinc is largely confined to the protection of steel from the action of the atmosphere and natural waters. It protects iron even when the coat is scratched or porous, but for severe service painting is advisable. The different types of zinc vary in purity from 0·01—1·5 per cent. impurity, but where the resistance of the zinc is due to the accumulation of protective corrosion products, as in atmospheric corrosion, impurities are usually an unimportant factor. In resistance there is little to choose between the various coatings, their life being mainly governed by the thickness.

In cases where the coated material is bent, it was thought that thin coatings were better than thick ones for resisting corrosion, but Evans

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* See *American Bureau of Standards*, **3**, 1929; **7**, 1931.

† For fuller details see McKay and Worthington, *Corrosion Resistance of Metals and Alloys*, Reinholt Pub. Corp., N.Y., 1936.

(*J. Inst. of Metals*, 1928, **40**, 99) showed that the reverse is true even though the visible cracks at the bends are more pronounced with the thick coats. Roetheli, Cox and Littreal (*Metals and Alloys*, 1932, **3**, 73) have shown that zinc has a useful resistance only in a narrow neutral range of aqueous solution. The protective hydroxide film is soluble in both acid and alkaline solutions with *p*H values less than 6 and greater than 11.

The effect of varying the temperature of distilled water on the corrosion of zinc is illustrated in the following table :—

TABLE XXXI.

Effect of Temperature on Zinc versus Distilled Water (Cox).

Temperature, ° C.	Corrosion Product.		Loss in Weight, mg./dm.²/day.
	Appearance.	Adherence.	
15	Gelatinous	Very good	10
54	Granular	Poor	12
65	Granular	Poor	500
93	Compact	Good	100
100	Enamel-like	Very good	20

Acids attack zinc very readily with evolution of hydrogen. A few corrosion rates for zinc are given in the following table, from which it will be seen that soft waters are more corrosive than those carrying calcium salts. Potassium bichromate is a film-forming substance.

TABLE XXXII.—*Corrosion Rates of Zinc.*

Solution.	Character of Test.	
	Steady Immersion.	Intermittent Immersion.
Sodium hydroxide, N. ...	90	450
Ammonium hydroxide, N. ...	60	60
Distilled water	60	—
Sodium chloride, N.	23	700
Potassium bichromate ...	0·7	1·5

Zinc is extremely susceptible to localised attack, but zinc coatings on steel are free from this defect, and consequently have a large field of usefulness.

Atmospheric attack of zinc is slow ; bright zinc rapidly tarnishes on exposure, forming a smooth adherent film of zinc oxide, carbonate and hydroxide. In industrial areas where the atmosphere is high in sulphur dioxide and carbon monoxide, a large portion of the film is washed off by rain. The corrosion rate is usually below 1 mg./dm.²/day (0·0002 in./yr.).

Most corrosion tests on sprayed deposits have been made on samples metallised by the wire pistol. A few tests were carried out by Rollason, in order to ascertain whether there is any appreciable difference between deposits made by the various processes when subjected to corrosion.

Ingot iron was used in the form of 4 × 2 × ⅛ inch strips with bevelled edges and with one hole for suspension from a glass hook. After sand blasting, the iron samples were coated by three types of metallising processes, the amount of sprayed metal being obtained by weighing.

One set of field tests was started in the grounds of Birmingham University and another group of specimens, including sherardised and galvanised steel, cast zinc, and a standard steel of known corrosion behaviour (X), was sprayed twice daily (except Sundays) with 3½ per cent. sodium chloride solution in a manner similar to that used by the Iron and Steel Institute Corrosion Committee.

Each side of the specimen was given one puff (0·03 c.c.) from a " Delta " spray at a distance of 6 inches and this was repeated at three heights, blank puffs being given at the side of the end specimens. For the first month the specimens were allowed to dry indoors, but subsequently they were placed outside so that the washing effect of the rain could be included in the tests. A number of painted specimens were also exposed to this intermittent spray test. The increase in weight of the samples and the time required for the first signs of rust to appear on the surface are shown in Table XXXIII. As yet the field tests have not progressed long enough to yield reliable results.

TABLE XXXIII.—*Accelerated Corrosion Tests* (*Rollason*).

	Layers.	Process.	Metal.	Spraying Distance.	Oz./ft.^{2}	Thickness, Inch.	Increase in Weight after 28 Days, Mg./cm.^{2}	Time for First Signs of Rust, Days.
1	1	M	Zn	N	1·105	0·0022	3·32	110
5	2	M	Zn	N	1·59	0·0031	3·31	160
*7	1	M	Zn	1 in.	2·67	0·0053	4·19	220
9	1	M	Zn	11 in.	0·94	0·0018	4·54	100
11	1	M	Zn	N worn	3·19	0·0063	3·29	> 220
16	1	S	Zn	N	1·92	0·0038	4·07	240
21	2	S	Zn	N	2·61	0·0052	4·26	> 240
W1	1	W	Zn	N	1·02	0·0020	3·01	220
W5	2	W	Zn	N	1·43	0·0028	2·97	> 240
W7	1	W	Zn	1 in.	1·03	0·0020	3·18	100
W8	1	W	Zn	11 in.	0·43	0·0008	3·04	59
†X	Standard steel						13·14	3
Zn	Cast zinc						3·73	
14	Sherardised				0·84		2·09	105
15	Galvanised				1·69	0·0036	2·56	170
12	1	M	Sn	N	1·08			4
24	1	S	Al	N	0·62	0·0027	3·80	26
W9	1	W	Al	N	0·38	0·0017	0·68	170
M4	1	M	Al-Si	N	1·58	0·0072	7·14	70‡

* Specimen 7 produced no white precipitate in full immersion tests.

† X, after derusting, lost 0·165 grm./cm.^{2} in 170 days.

‡ Layer shelled off in powdery mass.

M = Molten metal. S = Powder. W = Wire. N = Normal spraying distance.

It was noticed that the corrosion products on the sherardised samples were more readily removed by the rain than in the case of the other specimens, also the samples sprayed at normal distances from the nozzle offer a greater resistance to corrosion than those sprayed either near or far from the nozzle (*e.g.* 7, 9, W7, W8). Too few experiments have been made to yield very positive conclusions, but the general trend of these results is to show that all the zinc coatings made under best commercial practice have approximately the same rate of corrosion, and this life is limited mainly by the thickness of the deposit, which is in agreement with extensive tests on zinc made in America.* That the life of the sprayed samples is satisfactory was also shown by tests using 5 per cent. NaCl in a salt-spray cabinet. Samples metallised by each of the processes withstood 1,000 hrs. without signs of rusting.

When considered from the point of view of weight per unit area of sprayed surface, coatings applied by the " wire " process appear to be rather more efficient than those applied by the powder pistol.

Sutton and Braithwaite (1938) have carried out intermittent sea-water spray tests at Farnborough and marine exposure tests at Felixstowe and Singapore. The coatings which afforded the best protection of steel against corrosion were :—

(*a*) Coatings of electrodeposited zinc or cadmium or not less than 0·0015 inch of nickel.
(*b*) Sprayed coatings of aluminium or zinc (0·0028 inch).
(*c*) Coatings of zinc applied by the sherardising process or aluminium by dipping.

Most of the samples, when protected by any of these methods, showed little or no rust after one year's exposure in the corrosion tests.

Coatings of chromate-pigmented lanolin gave very good results in atmospheric exposure tests and sea-water spray tests.

Poor protection against corrosion by sea-water was afforded by :—

(*a*) Thin coatings of electrodeposited chromium applied over other metals.
(*b*) Coatings of aluminium applied by the calorising process.
(*c*) Coatings of phosphates.
(*d*) Coatings applied by the " gun-blacking " process.

Several investigators have shown that the protection afforded by zinc coats is mainly dependent on the weight and uniformity of the coat, and methods suggested to measure these two characteristics are given in Tables XXXIV and XXXV.

Aluminium.—Aluminium is inherently a very reactive metal and its resistance to attack by certain media is due entirely to the formation of an adherent impervious film of aluminium oxide, which is formed by oxidising substances, but is dissolved by strong alkaline and certain strong acid solutions.

Aluminium coatings are finding extending use for resisting sulphurous atmospheres and also for covering the steel or duralumin parts of aeroplanes. Aluminium-iron couples are found to behave in various ways depending

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* *A.S.T.M.*, 1936, **36**, (1), 103; *Bureau of Standards J. Res.*, 1936, **16**, 199.

TABLE XXXIV.—*Methods for Determining Average Weight of Zinc Coating.**

Method.	Details.	Comments.
Loss in Weight after Stripping	1. 100 gm. conc. sulphuric acid, 5 gm. arsenious oxide ; make to 1000 c.c. with distilled water.	Only average weight, No indication of uniformity.
	2. 100 c.c. conc. hydrochloric acid, 0·16 gm. antimony chloride.	Cessation of effervescence indicates end-point.
	3. 400 gms. lead acetate (cryst.), 1000 c.c. water, 4 gm. powdered litharge ; agitate, decant clear portion for use.	Lead replaces zinc and all traces must be removed.
Electrolytic .	Britton (*J. Inst. of Metals*, 1936, **58**, 211). 20 parts sodium chloride, 10 parts zinc sulphate, 100 parts water. Specimen made anode ; current density 1 amp./in.^{2}, removing 0·104 oz./ft.^{2}/min. Glazunov (*Iron Age*, 1934, **134** (1), 12, *Trans. Faraday Soc.*, 1935, **31**, 1262, used platinum electrode and conc. solution zinc sulphate.	Uniform current density must be applied to all parts therefore limited to simple shapes.
Hydrogen Evolution . . .	Use above antimony chloride solution and collect gas. 2·72 mg. zinc liberates 1 c.c. hydrogen at 20° C., 760 mm.	Convenient for testing article *in situ*.
Other Methods	Thermal, Magnetic, Chord.	

on the nature of aluminium and the exposure conditions. Evans has shown that steel specimens sprayed with aluminium have rusted in carbonate solution, at cracks in the coating, yet in sodium chloride solution the aluminium protected the steel (*i.e.* the necessary current density was obtained).

Aluminium is useful in exerting a protective effect on duralumin. In general, aluminium in contact with copper alloys, nickel, lead and chromium is rapidly attacked when exposed to sea-water, but accelerates the corrosion of magnesium. In sea-water copper and zinc bearing aluminium alloys have poor resistance to corrosion and pitting is common in both aluminium and its alloys.

Chromate additions reduce the corrosion of aluminium in refrigerating and air conditioning plant employing calcium chloride brine, and the metal has a good resistance to carbonates, chromates, acetates, nitrates and sulphates in the range *p*H 6·4—7·2.

In industrial atmospheres the rate of attack of aluminium is in the region of 0·5 mg./dm.^{2}/day and usually decreases with time of exposure. The attack by food products is usually 0—5 mg./dm.^{2}/day, although hot fruit juices

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* See L. Kenworthy, *J. Inst. of Metals*, 1937, **61**, 143.

TABLE XXXV.—*Methods for Testing Uniformity of Zinc Coatings.*

Name.	Details.	Comments.
Electrolytic Test . . .	See Table XXXIV. At intervals remove specimen, wipe, and immerse in 10 per cent. $CuSO_4$ solution, 5 sec. Adherent copper indicates removal of zinc.	Strips coatings at uniform rate irrespective of composition. Limited to simple shapes.
Preece Test .	Neutral copper sulphate, sp. gr. 1·170 at 60° F.; *e.g.* 33 gm. copper sulphate, 100 c.c. distilled water, neutralised with copper hydroxide. Make 1 min. dips at 60° F., until bright red copper adheres. Times (sec.) suggested by Groesbeck & Walkup :—sprayed = 55; Electrodeposit 60; hot dip 80; galvannealed 120.	Rate of solution decreases with increase in iron content of coating. Liable to premature end-point.
Dropping Test *	100 gm. iodine, 200 gm. potassium iodide, per 1000 c.c. of water. Allow to drop at rate of 1 drop/sec. on coating at angle of 45°. 22 drops removes 0·0001 inch zinc.	Not suitable when alloy is present.
Jet Test † . .	70 gm. ammonium nitrate, 8·1 c.c. conc. hydrochloric acid, per 1000 c.c. water. Stream impinges on the article. At 18° C. 20 c.c./min. removes 0·00002 inch/sec.	End-point is indicated by stained base metal.
Porosity Test .	20 gm. potassium ferrocyanide, 1 gm. magnesium sulphate, in 500 c.c. water. Use electrolytically, platinum cathode, 4 volts.	Blue colour produced on iron.

frequently give high figures. Concentrated nitric and acetic acids can be handled satisfactorily in aluminium, but dilute nitric, sulphuric, phosphoric and hydrochloric acids are corrosive. The attack by alkalis is severe even in the form of soaps and inhibitors such as sodium silicate, chromates and dichromates are used to protect laundry machines.

The resistance of aluminium to attack is vastly improved by the anodic treatment, a process for artificially increasing the thickness of the protective film. Even sprayed aluminium coatings can be anodised sometimes, preferably after polishing, but there is a strong tendency to strip the coating from the base.

According to Britton and Evans,‡ sprayed aluminium coatings on steel have given promising results. The tests, which were started in 1931, comprised thin (0·003 inch) and thick (0·006 inch) coats of three different grades of aluminium, including a very pure variety containing only 0·06 per cent. iron and 0·055 per cent. silicon: half of the specimens were tested as sprayed

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* S. G. Clarke, *J. Electrodepositors' Tech. Soc.*, 1933, **8**. No. 11.

† S. G. Clarke, *J. Electrodepositors' Tech. Soc.*, 1937, **12**. 1-18.

‡ *J. Soc. Chem. Ind.*, 1932, **51**, 217; 1936, **55**, 340.

by the wire pistol, whilst the others were "doped" with varnish before exposure. In addition, there were steel specimens sprayed with a thin layer of zinc as an undercoat and also as an overcoat on the aluminium. The specimens were exposed at each of four localities, representing urban, marine, country and mixed atmospheres. After four years' exposure at Selsey Bill (marine) none of the specimens showed any rust at all. The other specimens were kept under observation for longer periods and in 1937 all the specimens were completely free from rust, although in London there was evidence of some degree of corrosion of the aluminium, and parts of the specimens were black.

On certain specimens at Cambridge, scratch lines were ruled through the aluminium coating so as to bare the steel. On exposure, a little rust appeared in the scratches at first, but rusting soon ceased to develop and after 5 years was inconspicuous, although uncoated steel specimens suffered actual perforation in about the same time.

Sidery and Braithwaite* claim that better adhesion to the base material is exhibited by coatings of aluminium applied by the wire pistol than by coatings applied by the powder pistol, and this is an advantage where the aluminium coatings are exposed to sea-water spray, especially at elevated temperatures.

Turner* exposed at the Forth Bridge test panels coated with 4/1000 inch of aluminium by the wire and powder processes. The aluminium applied by the powder process failed in less than a month, whilst coatings applied by the wire process withstood two years before failure, which finally occurred along the "strokes" of the application.

In the intermittent salt spray tests carried out by Rollason, the aluminium-coated specimens showed widely different characteristics. The sample sprayed by the powder process exhibited rust spots within 26 days, the surface became grey and hygroscopic, whilst in the field tests rust appeared within 7 months. The sample sprayed with aluminium-silicon alloy by the molten-metal process was soon covered with a white deposit, and at the end of 70 days' exposure to the salt spray the coating was blistered and could be removed readily as powder. On the other hand the wire process yielded a specimen which remained unaffected and bright up to 170 days, after which period a few rust spots appeared. This is not unexpected since it is well known that the purer the aluminium the better is the resistance to corrosion.

Recently Gough and Sopwith have studied the effect of protective coatings on the *corrosion-fatigue* resistance of a 0·5 per cent. carbon steel, such as is used for streamline wires in aircraft. Rotating beam type tests were made in the presence of 3 per cent. salt spray. At the conclusion of the tests the aluminium-sprayed specimen was covered with a white deposit and it was stated that aluminium spraying plus enamel gives about as good protection as galvanising or sherardising, whereas spraying alone results in about 20 per cent. less protection. The corrosion-fatigue resistance of streamline wire steel in salt spray may be increased by a coating of aluminium plus enamel, to such an extent that the endurance limit at 20 million cycles is little, if at all, inferior to the fatigue limit of the bare steel in air; with aluminium spraying alone the decrease in fatigue resistance is 20 per cent. instead of 80 per cent. when uncoated.

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* *J. Inst. of Metals*, 1937, **60**, 64.

The relative resistance of 23 sprayed metals and metal combinations against the attack of corrosive agents occurring in flue gases (SO_2 — CO_2 — air) was determined by Pessel. The coatings were 0·008 inch thick and were tested for a year in a special spray tank. Of the coatings tested, only lead by itself and lead over Endura KA2 were found to protect the steel. Sprayed molten silver, copper and monel coatings were fairly intact, but showed a tendency to become loose on the edges which, of course, would destroy their usefulness in actual service where vibrations and heat variations are present. All the other coatings, including aluminised steel, were attacked severely, the corrosion products being mixtures of sulphites and sulphates.

Gruber sprayed aluminium, chrome-iron and 18/8 stainless steel in carbon dioxide, nitrogen and compressed air, respectively, and then exposed the specimens to hydrogen sulphide at elevated temperatures in a bubble tower of an oil refinery. It was found that the metals sprayed in the presence of inert gases were greatly superior in corrosion-resistance to those sprayed in the ordinary way using compressed air. Aluminium headed the list from the point of view of corrosion resistance.

Tin.—The use of tin coatings depends on :—

(*a*) It is physiologically inactive.
(*b*) It is not corroded by foodstuffs in the *absence of oxidisers.*
(*c*) Iron is cathodic to tin under certain conditions.

Block tin is only moderately resistant to acid solutions in the presence of air and tin coatings on steel corrode rapidly. In the absence of air the coatings become resistant due to their high overvoltage ; the hydrogen which develops on their surfaces increases the resistance to the flow of current and stops corrosion. If this hydrogen develops very rapidly by immersion in strong acids, evolution of the gas may occur and the polarisation effects no longer prevent corrosion. Tin coatings are frequently used on vessels carrying or processing milk. Even when strongly aerated milk seems to have only a slight action on tin, whereas fruit juices are much more corrosive, especially when hot. Tin resists the attack by distilled water and also the atmosphere to a high degree. Typical corrosion rates are given in Table XXXVI :—

TABLE XXXVI.—*Resistance of Tin against Various Media.*

		Mg./dm.²/day.
Dilute Acids, air free		0—3
Strong Acids, air free	6 per cent. Acetic	15
	6 per cent. HCl	60
Aerated Acids		500
Oxidising Acids—6 per cent. Nitric		600
Milk, 15° C.		1—2
Milk, 65° C.		6—9
Boiling Fruit Juice		200—300
Fruit Juice at Room Temp.		10—25
Caustic Soda		20—40

Lead.—The resistance to corrosion of lead is determined by the character of the film which forms on the surface. A protective layer is formed in the neutral range of *p*H about 3—11, which is dissolved by certain acids and alkaline solutions. Lead is thus resistant to sulphuric, sulphurous, chromic, phosphoric acids and to the atmosphere; is attacked by hydrochloric and hydrofluoric acids; and strongly corroded by nitric, acetic, formic acids and nitrate solutions. Some typical figures are :—

TABLE XXXVII.—*Resistance of Lead against various Media.*

	Mg./dm.^{2}/day.
Sulphuric Acid, 0-80 per cent., 15° C., quiet	0·5—10
Sulphuric Acid, 0-80 per cent., 15° C., agitation	100—300
Sulphuric Acid, 80-100 per cent., 15° C., quiet	10—350
Sulphuric Acid, 0-80 per cent., elevated temp.	1—200
Hydrochloric Acid, 1 per cent., cold, quiet	80—100
SO_2 and H_2SO_3 atmosphere	Nil
Caustic Soda, cold, quiet	80
Atmospheric	0·5

Painted Specimens.—Oil paints consist of a vehicle (linseed oil), drier and pigment. Since few coats are entirely watertight, the properties of the pigment should :—

1. Resist mechanical abrasion, rain and acids.
2. Inhibit attack of the metal by creating passivity.

Zinc chromates and red lead possess good inhibiting action and are useful constituents in the priming coat. Iron oxide resists abrasion but provides no protection of the steel at bare places. Attack of the steel is increased by :—

(*a*) Salt shut in below a paint coat.
(*b*) Invisible moisture film present prior to painting.
(*c*) Graphite in the priming coat.
(*d*) Loose rust and partially removed mill scale.

Rollason made a few tests on the influence of paint on the resistance of sprayed zinc coatings to an intermittent salt spray test. The steel specimens coated with zinc by metallising, sherardising and galvanising processes were given a single coat of paint of the following analysis :

	Per cent.		Per cent.
Indian red	53·2	Refined oil	13·3
Zinc chromate	16·0	Liquid driers	2·66
Boiled oil	13·3	White spirit	1·52

This paint was used because its behaviour on steel was investigated by the Iron and Steel Institute Corrosion Committee, but it is quite possible that the Indian red is an unsuitable constituent in a paint to be used on zinc.

The results are given in Table XXXVIII. It is clear that sprayed deposits of zinc offer excellent bonding for paint, and the greater porosity of the coating formed by the powder process is an advantage. The varnish impregnation of sprayed coating has been recently suggested by Reininger.

TABLE XXXVIII.—*Paint Tests* (*Rollason*).

Process.	Condition after 120 Days' Exposure to Intermittent Salt Spray.	Effect of Rubbing Surface.
Molten spray	Specks of white deposit	Good bond to base of paint
Powder ,,	Specks of cream deposit	Excellent ,, ,,
Wire ,,	Specks of white deposit	Good ,, ,,
Galvanised	Paint wrinkled; white deposit on bottom edge	50 per cent. paint removed
Sherardised	Crinkled paint; metal exposed in places	20 ,, ,, ,,
Paint only	50 per cent. area rusted	

Evans and Britton have also made field tests on painted sprayed coatings. Red iron oxide and grass-green chromic oxide paints were applied to aluminium. These paints retained their appearance far better than those applied directly to the steel, since in the British climate failure of paint due to under-rusting proceeds more quickly than the deterioration of the paint starting from the outside.

Sidery and Braithwaite state that under conditions of exposure to marine conditions in tropical waters over a period of 200 days, aluminium coatings sprayed by a " wire " pistol gave excellent protection to samples of mild steel sheet, high-tensile nickel-chromium alloy steel strip (approx. 0·3 per cent. C, 4·0 per cent. Ni, 1 per cent. Cr) and duralumin sheet, but it was observed that no benefit was derived by the application to the metal-sprayed surfaces of supplementary organic protectives such as stoving enamel or pigmented oil varnish. Indeed, samples to which coatings of stoving enamel had subsequently been applied showed greater deterioration than did those carrying sprayed coatings of aluminium only. Slightly increased protection was obtained by synthetic resin varnish on zinc coatings.

On account of the comparatively high porosity of the coating, metal-sprayed surfaces appear to require about twice as much enamel or varnish as ordinary metallic surfaces for the production of films of normal appearance. The total weight of the protective scheme per unit area thus becomes somewhat high and tends to render the scheme less attractive in cases where weight is of prime importance, as, for example, on aircraft.

It appears desirable to search for organic protectives which can improve the protective effect of sprayed coatings without unduly increasing the weight.

Resistance to Oxidation at Elevated Temperatures.*—There are several processes by which an aluminium-iron alloy can be formed on the

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* Hopfelt, *Arch. Wärmewirtsch.*, 1930, **11**, 243; Kelley, *Trans. Amer. Electrochem. Soc.*, 1923, **43**, 357.

surface of ferrous articles for protection from scaling due to exposure to high temperature. Aluminising is one of these processes (patented). It consists in spraying an aluminium coating on to the article to be treated, and by means of a suitable heat-treatment, alloying the aluminium with the base metal. Various dopes are applied to the aluminium to prevent oxidation during the treatment. During the process of aluminising steel, a compound coating is formed, which is composed of three layers:—(*a*) next to, and fused into, the steel, is a solid solution of iron and aluminium; (*b*) next comes a layer of iron-aluminium alloy ($FeAl_3$), together with a slight excess of free aluminium; (*c*) finally comes a thin coating of aluminium oxide. The outer layer (*b*) usually flakes away after several hours at temperatures over 800° C. As long as the aluminium layer (*a*) remains on the surface of the steel, scaling is impossible, and it is only when aluminised steel is heated above 1000° C. that an accelerated rate of penetration of the aluminium into the steel reduces the percentage of aluminium in the coating sufficiently to allow oxidation to commence.

Aluminising can be used with advantage at temperatures up to 1000° C.

At the present time in Great Britain only the wire type of metallising process is employed in the production of aluminised surfaces for resisting oxidation. Rollason made tests, therefore, to find how the deposits made by the various processes compared with each other. Samples of mild steel were sprayed with known amounts of aluminium or aluminium alloy and were then subjected to four commercial preliminary treatments. The different treatments, patented in England, Germany, and France, were carried out as follows:—

English: coat specimen with bitumastic paint, heat rapidly to 780° C. for 10 minutes.

German: coat specimens with water glass, heat rapidly to 800° C. for 15 minutes.

French: coat specimens with saturated solution of borax and anneal at 600° C. for ½ hour.

English: cadmium-aluminium alloy—heat rapidly to 900° C. for 10 minutes (this alloy and its use for this purpose are the subject of British Patent 400,752).

The main object of these treatments is to prevent oxidation of the aluminium while the diffusion layer is forming. After treatment, the samples were heated for 5-hour periods at 900°-925° C. in a muffle, after which they were quenched in water; this has a very drastic effect on any surface scale. The specimens were inspected and weighed periodically. For comparison, samples of mild steel, Silal, and 18/8 nickel-chromium steel were included, together with steel specimens coated with 18/8 austenitic steel and with the alloy nickel 65, chromium 15, iron 20 per cent. sprayed from wire. The two latter specimens were previously annealed at 1100° C. for 2 hours without protection in order to form a diffused layer. After the treatment one specimen coated with nickel-chromium showed two blisters, whilst the specimen sprayed with austenitic steel oxidised badly.

The bitumastic paint protection appears to be very successful, and the wire process yields the best results. Even after 250 hours under test the

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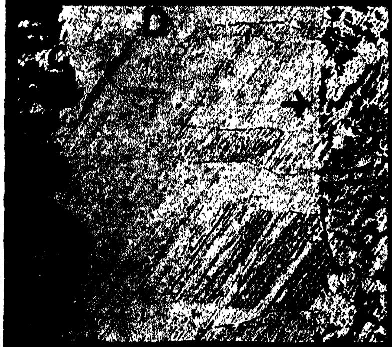

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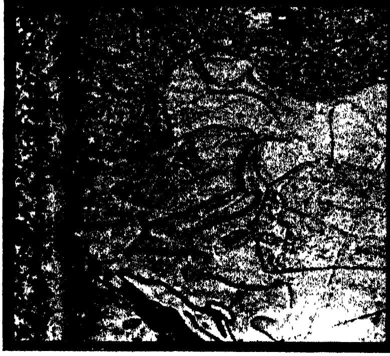

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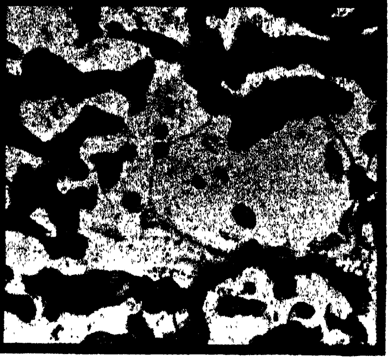

C = Sprayed Coat. D = Diffused Layer. P = Base Plate.

FIG. 163.—Sprayed Aluminium by Powder Pistol. Bitumastic Coating Heated 780 C. for 10 mins. Etched. × 200.

FIG. 164.—Sprayed Aluminium-Silicon Alloy by Molten Metal Process. Treated as Fig. 163. × 200.

FIG. 165.—Sprayed Aluminium as Fig. 129 but Annealed 2 hours at 1000° C. Columnar Crystals ; Border (↑) ; Concentration of Pearlite (P). × 175.

FIG. 166.—Sprayed Nickel-Chromium-Iron Alloy by Wire Process. Heated 2 hours at 1100° C. Penetration along Grains (↑). × 250.

FIG. 167.—Sprayed 18/8 Steel by Wire Process. Heated 50 hours 900° C. Note Superimposed Structure in Plate. × 200.

FIG. 168.—Sprayed Mild Steel by Wire Process, after Heating at 900° C. for $\frac{1}{2}$ hour. Coalesced Oxide (Half-Tone). × 400. (Rollason.)

specimen coated with nickel-chromium-iron showed a negligible change in weight. Results are shown in Table XXXIX.

TABLE XXXIX.—*Duration of Heating to Cause* 50 *per cent. Loss in Weight* (*Hours*).

Spray Process and Metal.	Treatment.			
	English. Coated Bitumastic Paint: Heated 760°C. for 10 minutes.	*German.* Coated Waterglass: Heated 800°C. for ½ hr.	*French.* Coated Borax: Heated 600°C. for ½ hr.	None
Wire, aluminium	140	150	45	
Wire, cadmium-aluminium				130
Powder, aluminium	90	80	60	
Molten, aluminium-silicon	85	50	15	
Wire, 18/8 nickel-chromium steel				50
Wire, nickel-chromium-iron				>250
Mild steel plate				7
Stainless 18/8 plate				300
6 per cent. silicon cast iron 0·8 in. diameter				100

Average weight deposited: aluminium 0·035 grm./cm:^{2}; 18/8 steel 0·24 grm./cm.^{2}; Ni-Cr-Fe 0·30 grm./cm.^{2}

The structures of these samples are shown in figs. 129 and 163 to 167. In all cases the pearlite is concentrated in the front of the diffusing layer, and in the initial stage this layer occurs in the form of finger-like masses. After treatment at 900° C. this latter characteristic is lost, the diffusion layer is most frequently parallel to the surface, as shown in fig. 165, but in one sample the aluminium had completely diffused through the specimen in isolated places with the production of large crystals. At these places oxidation occurred with the production of round shell-like masses of oxide; this is possibly due to the lower aluminium concentration in these areas. Local oxidation also occurred occasionally on the edges where either metallising or preliminary treatment had not been perfect.

Ageew and Vher have shown that the diffusion of aluminium occurs in two stages: (*a*) dissolution of the iron in the liquid aluminium, with the formation of a solution in equilibrium with the solid phase at a given temperature; (*b*) diffusion of the iron-aluminium solution into the iron. The main principle underlying the above treatments is to initiate these two reactions. Subsequently, at 900° C., the diffusion of the iron-aluminium solution into the iron occurs rapidly at first, but decreases as the concentration of aluminium is reduced. The reason for the columnar grains in the diffusion layer and the concentration of pearlite in front of them has been explained by Benedicks as due to the aluminium being more soluble in the ferrite than in the austenite. With suitable concentration of aluminium, ferrite crystals (in which carbon is not appreciably soluble) are formed, and these grow slowly inwards. Bardenheuer and Müller have shown that oxides present in the sprayed coating have a harmful effect on the diffusion process, and this is possibly the cause of the difference in resistance of the samples sprayed by the powder process; silicon retards the diffusion rate in the case of the samples treated by the molten metal pistol.

Fig. 167 shows what appears to be two structures superimposed.

Bardenheuer and Müller have studied the metallic diffusion of several metals, sprayed by the Schori process, into iron. *Nickel* diffused into iron only with great difficulty, although iron permeated the nickel layer to the extent of 19-28 per cent. iron. Oxides present in the coating had a harmful effect and diffusion occurred more readily into a 0·75/0·88 per cent. carbon steel where the carbon reduced the effect of the oxide. *Chromium powder* (97·9 per cent.) was easy to spray, but the pistol flame had to be shorter than in the case of nickel. The chromium readily diffused, forming columnar crystals and the coating could withstand hammering without tearing off. Mixtures of *nickel* and *chromium powder*, sprayed and heated at 1150° and 1300° C., revealed the fact that the nickel diffuses better and the chromium less than either metal singly, although this is contrary to the statement of Van Drunen. The theory suggested by the German workers is that as nickel is more noble than iron it cannot retain the oxides which are formed during the spraying of the nickel coating. The outside surface of the iron becomes covered with an oxide skin which prevents the diffusion of nickel. The chromium is less noble than iron, the oxides are retained by it and the iron sample remains bright, allowing unoxidised chromium to diffuse. With a mixed powder of chromium and nickel the chromium absorbs the whole of the oxygen, so that the nickel and the remainder of the chromium can diffuse. Mixtures of aluminium (50) plus chromium (50) and aluminium (30) plus nickel (70), yielded coats which crumbled away. A mixture of nickel (80) and silicon (20) produced a very hard layer, unmachinable, without blistering. Mixtures of all four metals were also tried.

Sound and serviceable protective coatings can be produced on soft steel from sprayed metal coatings with the help of diffusion. The advantages are (1) the economic use of the cementation medium and (2) ease of handling large articles. The disadvantages are (1) the necessity of using a pistol and associated equipment, (2) lower concentration than embedded cementation, (3) the poor surface, (4) the necessity of using a non-oxidising atmosphere or some surface dope to reduce oxidation during diffusion treatment.

Solid Bodies Built Up by Spraying.—In 1925, Turner and Ballard* built up comparatively large solid bodies by the metal-spray process. In a steel mould, copper, zinc, tin, aluminium, and iron bars were produced by spraying longitudinally for one set of tests, and transversely for a second set. It was found that the bars so produced could all be sawn, filed, planed, turned and machined much in the same way as solid metals. The bars had a clear metallic ring when struck, and this latter point was of especial interest, because it had been stated by Arnold that such bodies entirely lack metallic resonance. To demonstrate this fact, bell-shaped masses of sprayed zinc, aluminium, and bronze were built up by spraying

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* *J. Inst. of Metals*, 1924, **32**, 291-312.

around a steel mandrel, which was removed when sufficient thickness, about $\frac{1}{4}$ of an inch, had been sprayed. These bells were exhibited at the autumn meeting of the Institute of Metals, and all possessed a definite metallic ring, although built up of interlocked particles. The zinc bell did not have a noticeable ring on the day it was sprayed, but developed such resonance in the course of a few days. Thus a change in zinc apparently occurs after spraying, a point worth bearing in mind.

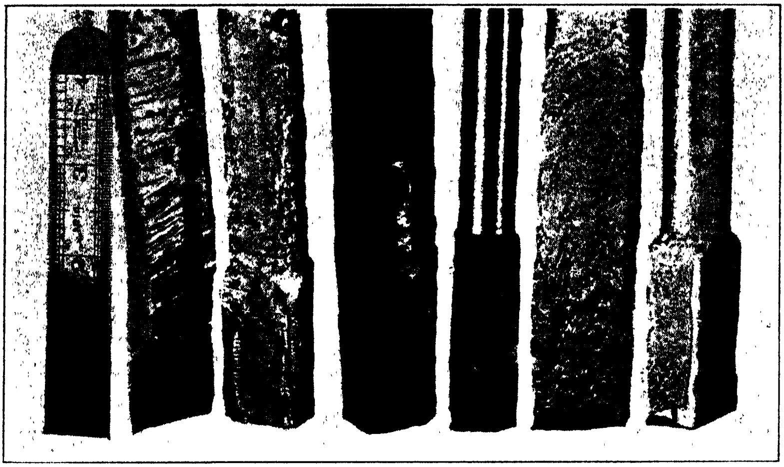

FIG. 169.—Blocks of Metal Built up by Metal Spraying. Left to right, in pairs: tin, copper, zinc (Turner and Ballard). Scale shown in inches.

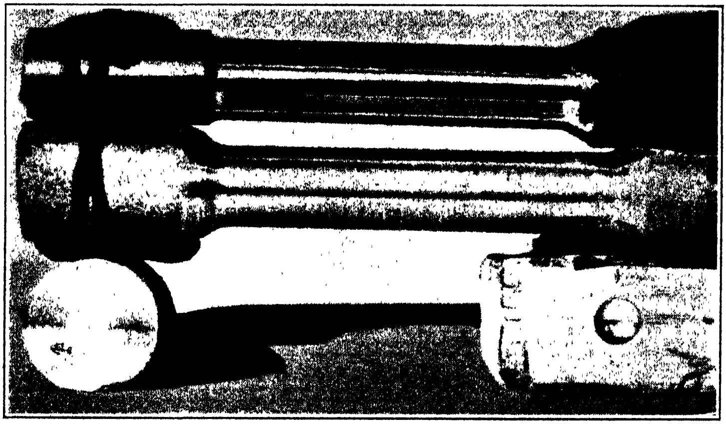

FIG. 170.—Machined Bars of Sprayed Copper, Zinc, and Tin (Turner and Ballard). Slightly less than actual size.

Fig. 169 shows some bars obtained by spraying, such as were used for preparing tensile, shock and hardness test specimens.

Sprayed metal can be chipped with a chisel without flaking in one direction, but it is liable to flake in another one at right angles to it. If a bar of this material, which has been sprayed longitudinally, be turned in the lathe it will be found that on two sides the metal is indistinguishable from cast material, while on the other two sides, at right angles to the first, a comparatively rough surface is often, though not always, obtained; this is shown in fig. 170, which illustrates bars of copper, tin, and zinc built up by means of metal spraying and subsequently machined.

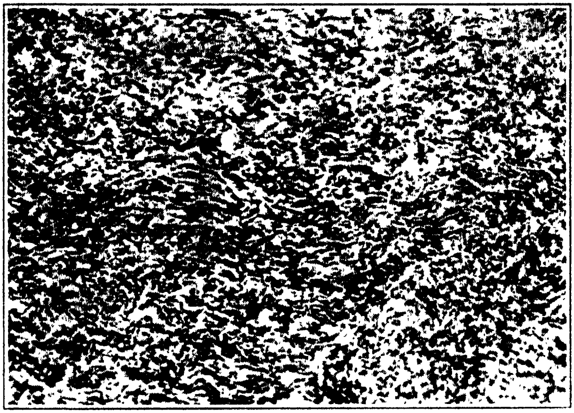

Fig. 171.—Photomicrograph of Sprayed Zinc (Turner and Ballard). × 100.

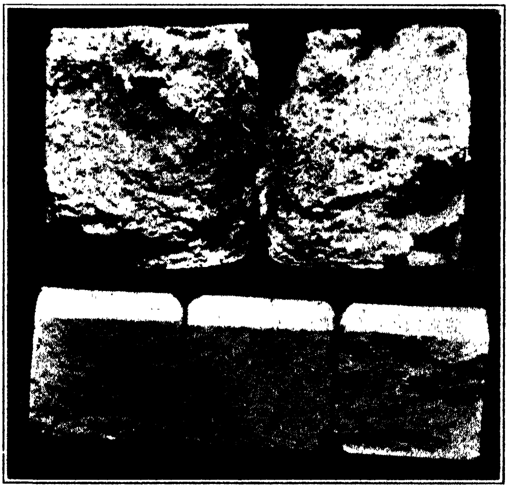

Fig. 172.—Izod Test Piece Fractures. × 2.

The photomicrographs of sprayed zinc shown in fig. 171, and those of copper shown in fig. 142, were obtained from such samples, sectioned longitudinally, and explain the liability to chip in one direction.

From these bars of sprayed material tensile and shock test pieces were machined. As would be imagined, the strength was very low, but it is remarkable that it was possible to machine an Izod test piece from sprayed zinc and to note the difference in strength between the tests taken parallel to and at right angles to the laminations. The fractures may be seen in fig. 172. The larger ones being those of a piece of zinc sprayed transversely.

Typical tensile strengths of sprayed metal are:—

	lbs. per sq. in.
Zinc, - - - -	4,610
Aluminium, - -	4,900
Copper, - - -	4,400
Tin, - - - -	3,300

Applications and uses of metal spraying in building up shafts are discussed in Chapter VII.

CHAPTER VI.

COMPARISON OF THE METAL SPRAYING PROCESS WITH OTHER METHODS OF METALLISATION.

In the present chapter an attempt has been made to outline the better known methods of producing metal coatings upon metallic or other surfaces, and to compare such methods with the metal-spray process, both with regard to the method of application and to the properties of the resulting deposit.

Necessarily there are some methods of metallisation with which the spraying process cannot favourably compete, but there are others to which it constitutes a serious competitor.

In certain types of work, such as, for example, in the metallisation *in situ* of completed structures, the metal-spray process even deserves the entire monopoly.

Bronzing.—The word " bronzing " is derived from the Italian " bronzino," a brown colour, and was originally applied to the browning of metallic articles, but has now come to be applied to the production of all colours alike.*

But while the word principally refers to the production of various colours on metallic objects by chemical and electrochemical means, it applies also to the superposition of metallic powders, generally called bronze powders whatever their colour, or of thin metallic sheets by means of varnish or other adhesive material on to the article to be covered. Bronzing by means of metallic powder or foil is the only method which will here be considered.

It has often been shown that the Egyptians used sheets of beaten gold 3000 years or more B.C. to cover wooden statues or similar objects made from base materials, thus decorating them and giving to them the appearance of massive gold. Owing to the high cost of gold, efforts have naturally been made to beat the sheet metal as thin as possible, and thus gold leaf can be beaten so thin that the mass of a sovereign provides sufficient to cover the surface of a full-sized equestrian statue.

One can look back with some certainty to the beginning of the manufacture and use of gold leaf, but concerning the use of the scrap, which is produced in considerable quantity in this process, ancient history tells little or nothing.

What is possibly the first mention of the use of " gold bronze " obtained from the scraps of gold leaf is made in the Leyden Papyrus† of the third century A.D., at least 3000 years after the preparation and use of gold leaf

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* Hiorns, *Metal Colouring*, second edition, 1902, p. 1, Macmillan & Co.

† Theobald Wilhelm : "The Preparation of Bronze in Past and Present," *Dingl. Polyt. Journ.*, 328.

for gilding was known. It seems incredible that the ancient Egyptians did not know of the preparation of bronze colour from gold leaf, and one may assume that it is only by accident that the preparation of bronze powder is not mentioned throughout this period in the manuscripts which have been consulted. In later days the scraps or trimmings were ground to an impalpable powder in a mortar and mixed with a clear adhesive solution such as gum arabic, in order to produce a golden liquid which could be employed for writing or painting the articles to be gilded. The procedure is very similar to this to-day, though it is true that where its presence is not detrimental, linseed oil, a resinous solution, or similar adhesive is used, in which the gold particles are either rubbed down or with which the article to be gilded is coated before being dusted over with the metal powder.

The process utilising powdered gold is a direct descendant of the old gilding process with sheet gold, since it was soon realised that the gold powder obtained from the gold scrap was a less expensive substitute for leaf gold itself. To-day in the age of substitutes we are no longer satisfied to use pure gold, but prepare powders from base metals such as copper, tin, zinc, aluminium, and some of their alloys. Methods of preparing base gold and other bronzes were known in the Middle Ages, but with the exception of the Leyden Papyrus, already mentioned, which contains some fifteen recipes for the preparation of base gold and silver bronzes for lettering and for the decoration of parchments, no further historical information has been found upon this subject. In any case, the modern bronze powder prepared from base metals only became generally known at a much later date.

Bronze powder does not appear to have been much used in the early Middle Ages, apparently because of the easy oxidation which it undergoes on exposure, resulting in the metallised surfaces quickly losing their shine and becoming matte and darkened. This same difficulty is still encountered to-day, and only overcome by the choice of suitable alloys and the use of protective coatings or lacquers, applied in order to give the base bronzes a more lasting lustre.

But in the early days these protective measures were not known, and it thus came about that bronze powder made from base materials only reappeared in the seventeenth century. It was then used in the town which to-day, together with its neighbour, is one of the manufacturing centres of the world for this product. In these towns, Nuremberg and Fürth, there were recently well over fifty bronze-powder factories in operation, of which the largest yearly employed for this purpose about 500 tons of metals of all colours. Some of the numerous metallic colourings which are common to-day were first imparted to these Nuremberg bronzes nearly three hundred years ago. In those days the colourings were produced by mixing together powdered copper, brass, tin, and iron, and it was not until the eighteenth century that Hotzinger discovered the art of heating the powders in flat open vessels whereby they were given the bright colours now called temper colours.

One particularly fine bronze was prepared by mixing the leaf metal with gum water and rubbing it down in a mortar. The present-day manufacture is carried out as follows on exactly the same principle: The metal is beaten to thin sheets, torn in stamping mills to a fine powder, sorted to various grades of fineness, and polished in special machines with the addition of oil. The finished powder is then mixed with a thin solution of gum arabic and squeezed between heavy, smooth rolls. Finally, it is led into long troughs in which it deposits from the gum solution quickly or slowly according to the grain size.

The technique of bronze-powder manufacture was quite primitive until about one hundred years ago. Thin sheets, which were either the scrap of leaf metal manufacture or were specially prepared, were powdered in a mill whose vertical shaft was surrounded by several sieves. The leaf metal was ground on the sieves by brushes fixed to the shaft. These brushes worked the material through from one sieve to another, and from the third the powder was taken out by syphoning off the water containing it. The powder so obtained in various degrees of fineness was dried. A description of the modern apparatus for preparing bronze powder is not within the scope of this book, and it need only be stated that the first complete mechanical rubbing mill was designed by Georg Benda, the founder of the Nuremberg factory, which is to-day one of the most reputable works of its kind and has been established for more than a century.

J. Brandeis of Fürth first succeeded in 1850 in devising a commercial method for the preparation of bronze from coarse pieces of metal solely by mechanical means. About the same time Bessemer set in operation at Baxter House, Charlton, England, a plant for the manufacture of bronze powders from solid blocks of any common metal. His process was extraordinarily successful and was kept a profound secret for many years, yielding him in the meantime a very considerable revenue.*

From this time onward dates a tremendous development of the whole industry, especially after the stamp works were introduced a few years later by Quirin Schmidt, and the uses of bronze powder and leaf metal are now almost as manifold as those of oil colours and of other sorts of paint.

In general, two methods of bronzing may be distinguished: firstly, that of working with a dry powder by scattering it upon a surface covered with some liquid binding material or adhesive; and secondly, that of using the powdered metal together with a liquid adhesive such as paint, the liquid being called "bronze tincture"; this latter method of bronzing is naturally the more simple.

Considerably better and more shining layers may be obtained, however, by those bronzing processes in which the metallic powder is scattered or rubbed on to an adhesive foundation; this latter is prepared with varnish or lacquer size and the bronze is applied some time after, when the foundation material is almost dry. The powder is rubbed on with a brush or wad and assumes under this treatment a beautiful and lasting lustre. Naturally the great industries employing bronzing processes do not work by hand labour, but, in fact, use an apparatus somewhat similar to the modern metal-spraying pistol for the application of both the adhesive and of the metal powder. Or, in some cases, the bronze tincture itself is sprayed directly on to the articles to be metallised. The most general method, however, is that of applying metallic powder to a prepared adhesive coating.

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* Autobiography of Sir H. Bessemer, published at Offices of Engineering, Bedford Street, Strand, London, W.

The apparatus shown in fig. 173 is intended for hand work and may be used much in the same way as the now common aerograph paint-spraying pistols.

There is hardly any material which cannot be metallised by this bronzing process, although many bodies first require a certain preparatory treatment. Thus, for example, wood and picture mouldings are first soaked with a thin glue or size solution, and a layer consisting of finely powdered chalk with size and water is then applied over this. Only after this layer has dried and is polished smooth comes the adhesive foundation for the bronze which itself is later applied. The chalk may be replaced by colours such as chrome yellow or ochre to enrich the tinting effect and to serve as a basis for the gold bronze. A white base is, however, generally preferred, as it more readily permits the detection of faults or breaks in the bronzed coating.

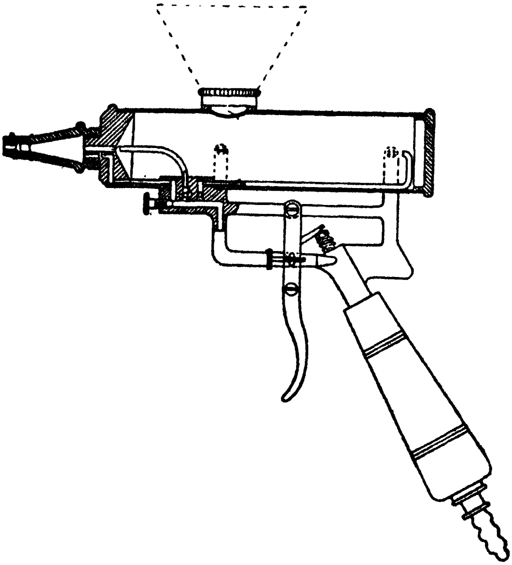

FIG. 173.—Metallic Powder-spraying Pistol for Scattering Bronze Powder over Prepared Sticky Surfaces.

If wood is to withstand weathering, the preparatory treatment is done with linseed oil and oil colour; the bronze holds firmly on to wood prepared in this manner and cannot readily be chipped off. A similar foundation of linseed oil is used for plaster of Paris, and also for metal articles such as iron wall-brackets, lamps, and so on. In this case the oil is forced by moderate heating to press into and fill all depressions and inequalities of the surface, while the excess of oil vaporises; only then is the bronze rubbed in. This procedure is also followed with glass in the preparation of picture frames and trade advertisements, some colour and a solution of gelatine being frequently used as an adhesive.

The bronzing process is of special utility in the imitation of old metals such as old gold and silver; in this case a foundation layer of oil colour is firstly applied, and when dry the bronzing is carried out in the usual way. The bronze colour is partly polished on the raised portions of relief art objects and the effect so produced is extremely beautiful. Many museums possess surprisingly good imitations produced in this manner of famous old art metal objects, the originals of which are necessarily only accessible at one place.

Finally, mention should be made of the decoration of ceramic articles, porcelain, and so on, which are also covered by metal foil or powder applied to oily foundations. For this purpose specially viscous oils are used, which burn away in the subsequent heating without leaving any residue. Naturally, a "burning-in" of the metallic decoration is necessary for almost all ceramic products, as with such articles which must come in contact with water the metal would otherwise soon be rubbed off. This process has been discussed at some length because it is the oldest method of metallisation known, and because, even apart from the apparatus employed, it is similar in many respects to the metal-spraying process dealt with in this book, and it also can be used on almost all imaginable materials.

Compared with the metal-spraying process, bronzing possesses the advantage of much greater simplicity of operation. This advantage is, however, more than compensated for by the greater solidity, hardness, and strength of the true metallic layer sprayed on in the molten state by Schoop's process. It is clear that the adhesion of the bronze particles in a solidified lacquer is not comparable with a metallic coating whose particles, without any adhesive material, form a complete whole. This difference in the two methods of metallisation carries with it the further advantage for sprayed metal layers that their strength is not limited by thickness, while with bronzing this is not the case. Bronzing will maintain its popularity in all cases where cheapness and ease of application overweigh strength, hardness, resistance to corrosion and abrasion. These and other properties of a like character are not always necessary, and bronzed coatings do not, therefore, suffer serious competition for many purposes of decoration.

Fire Gilding.—The Leyden Papyrus contains a recipe for preparing gold liquid which can be used for writing and painting ; it consists of quicksilver in which gold leaf is dissolved until the desired consistency of the mass is obtained. Heracleus also wrote several descriptions of methods for the preparation of dry powdered gold, in which it is noted that one should add gold to quicksilver, rub them well together, and then heat the mixture until the quicksilver is driven off, leaving a gold residue which is powdered in a mortar. In this process lies the fundamental principle of fire gilding, so that it is really remarkable that the step from this method of preparing gold bronze to the present-day fire-gilding process was not made directly after the publication of the recipe.

The elder Pliny described fire gilding by gold amalgam in the same way as it is carried out to-day. It may be best used on pure silver and on bronze, but also after suitable preparation on other metals—for example, copper, brass, and iron. However, only those metals whose melting-point is higher than the temperature necessary for volatilisation of the mercury may be gilded in this manner. As is the case with almost all other metallising processes, fire gilding demands as clean and matte a surface as possible. This condition is fulfilled by first annealing the article to free it from grease and organic impurities, and then treating it in the heated condition with an acid pickling mixture, subsequently thoroughly washing and drying it.

The amalgam consists of about two parts of mercury to one part of gold, and is as soft as wax. Before it is applied, the surface must be treated with " quickening " solution, *i.e.* a solution of nitrate of mercury. Any brushes or spatulas used for applying the amalgam are also dipped into this solution to assist the adhesion and spreading of the amalgam on the surface. The article is next heated to a suitable temperature, at which the mercury is driven off. If it is desired to obtain a thicker gilding, the same treatment is repeated several times. The principle of this process is that mercury combines not only with gold but also with the metal to be gilded ; the two amalgams intermix, especially when hot, so that if the quicksilver is subsequently driven off at a higher temperature, surface alloying between the gold and the foundation metal occurs. When the process is repeated several times, fire gilding is the most lasting and reliable method of gilding ; although the coating requires subsequent treatment since the vaporised mercury leaves behind in the gold many minute pores which must be removed by polishing. We see, therefore, that this process which gives such good results is not easy to carry out on account of the previous treatment required, and because of the special care necessary in working. Added to these technical difficulties must be considered the menace of the very poisonous mercury vapour to which the workers are exposed. As a result of this the process has been less used during the last few years, and from the hygienic point of view one may welcome a competitor to the old fire gilding in the form of the metal-spray process.

Even though the alloying of the metals in the older process produced a firmer adhesion of the layer, still the more simply operated and danger-free spray work, which certainly gives good results, is to be preferred on many grounds, and especially if one bears in mind the possibility of making a thick coating which may be partly or wholly of other metals than costly gold.

Sheffield Plating.—The metallisation process, usually called Sheffield plating, is not to be confused with electro-plating processes, in which metal is deposited upon the article to be coated from an electrolytic bath by means of the electric current. Sheffield plating involves the laying of noble metal sheets upon a baser metal and then uniting them by mechanical means ; heat is applied, and a certain amount of alloying between the several layers actually takes place. The sheet to be plated is placed between two sheets of the coating metal and passed through rolls, whereby the great pressure and heating which results unites the three layers into one single plate, which can be treated further until rolled to the desired thinness. The union of the metal so caused is so intimate that the sheet produced may be formed and worked in almost any manner without the individual sheets becoming loosened or separating from one another. The metal to be covered is almost always less valuable than the coating metal, because the aim of the process is to manufacture objects, which would be too expensive if made from solid noble metal, more cheaply and yet similar in appearance to solid articles by embodying in a thin noble metal shell a thick body of less valuable material.

This idea is much older than electro-plating, and long before the silvering of copper articles by the electrolytic method was known, Bolsover in England had used the process described above. As a foundation metal, copper was generally chosen because it was easily rolled into sheets, and, above all, it combined excellently with silver. Nickel silver is still better adapted for this purpose, although not cheap, containing as it does nickel and tin, the price being greater than that of copper alone. Sheffield plated articles, provided their outer layers are not too thin, possess greater strength and wearing properties than the solid noble metals themselves; this is due partly to the hardening which arises from the mechanical work to which the sheets are subjected. They are not only welded together as a result of the pressure and heat, but also go through a densening process which gives them, and especially the two outer noble metal layers, a much greater power of resistance against mechanical influences, and, therefore, against wear in daily use, than is possessed by the normal noble metal sheet used for such articles.

Frequently plates covered by electro-plating, etc., are subsequently given this hot-rolling process, which leads to the coating welding with the foundation metal.

The rolling-welding process described above for silver and copper may with equal success be applied to many other metals, *e.g.* pure aluminium on duralumin and nickel on mild steel. Compared with the metal-spray process, on the other hand, Sheffield plating possesses the natural disadvantage that its use is limited to metals, whereas with the metal-spray process no such limitation exists.

Also in favour of the metal-spray process is the fact that it need not be exclusively used upon the raw material, but may be applied to finished articles. Nevertheless, Sheffield plated articles are of such excellent quality that they need fear competition only on the score of cost.

The metal-spraying process does not primarily aim to compete with such processes as are used for the beautification of less valuable materials, having its greatest scope and success in the fields of rust protection and preservation from corrosion. Nevertheless the introduction of metal-clad sheets is increasing.

Tinning.—So far we have only considered those metallisation processes whose main aim is the beautification of art or other objects by the application of noble metal coatings or of suitable imitations.

We now come to discuss a different class, namely, those intended primarily for rust protection of such articles as are employed in the arts and industries; not for decoration but for utility in the general sense of the word.

The tinning process is applied principally to objects of iron and steel, but also, in lesser degree, to brass and other metals. To protect iron against corrosion any metal may be used which is not attacked by air and moisture, but, on the whole, tinning and zincing may be regarded as rust protectors *par excellence.* One of the principal applications of the tinning industry is the manufacture of tinned sheet iron. This is a mass-production process which is carried out on an enormous scale according to two different methods, the English and the German, differing in certain details, but similar in principle and both giving almost equally good results.

Before coming in contact with the tin the sheet iron or steel must be thoroughly cleaned from dust and grease and the oxide of iron which forms during the rolling operation as a scale upon the surface.

The cleansing is accomplished either by chemical processes employing dilute acids (sulphuric, acetic, etc.) or by mechanical scrubbing with sand or application of the sand blast. By rubbing with sand the surface becomes uniformly rough, which favours firm adhesion of the tin in the bath. According to the English process, before the sheets arrive at the tin bath they are softened by an elaborate annealing and gradual cooling process while being protected from the air, since in the hard and brittle condition in which they leave the rolls they are useless for working up into the thousand and one articles which are made from tin plates.

The tinning machine is essentially a system of rolls for conducting the sheets singly down through a flux—zinc chloride or a mixture of zinc and ammonium chlorides—into a tin bath underneath, maintained at a temperature of about 300-350° C., and then up through palm oil in the exit compartment. The palm oil serves to protect the tin from oxidation or discoloration while being cooled, and the final rolls in the oil press off excess tin, thus regulating the thickness of the coating. Metallographic investigation has shown that a tin-iron alloy is formed under the correct conditions at the region of contact; this naturally makes an inseparable union between the iron and the tin. Generally, the tinned sheets are polished, or given a crystalline pattern by etching.

In a similar manner wires and small irregular iron articles are tinned; the latter are, however, usually given a thin coating of copper so that the tin will more readily adhere. The advantage of the process, which may also be used for wires, compared with the metal-spraying process, is that larger surfaces may be coated at the same time, an advantage which, however, carries with it the disadvantages that great masses of molten metal are constantly in use. This condition is, however, of comparatively small importance, and not enough to sink the balance in favour of the spraying process.

The immersion tinning process for sheet is at present a field in which the metal-spray process can scarcely compete. The tinplate industry of the United Kingdom alone consumes about 10,000 tons of tin per annum, valued at over £1,500,000 sterling. Tinplate is specially applicable to the production of vessels for holding articles of food, or for cooking utensils, as tin is not readily attacked by vegetable juices.*

Despite these facts the metal-spray process is obviously far superior in certain directions to the older process, for it alone permits the tinning of large finished structures or vessels, such as the many large castings used in the foodstuffs factories, and, moreover, with this process any previous coppering or similar preparation is unnecessary. The same applies to constructional parts made of cast iron which are only treated with great difficulty by molten metal in the immersion tinning process. In this field lie highly important possibilities for the Schoop process.

Galvanising.—Zinc is even more largely used than tin for the protection of iron, though its introduction is of later date than that of tin. As compared with tin, zinc is cheaper and quite as easily applied. The process, misnamed "galvanising," is that of coating by immersion in molten zinc after first removing the scale by pickling in acid. Galvanised iron is employed for corrugated sheets, roofing, buckets, wire, and for innumerable other objects

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* Turner, T.: *The Metallurgy of Iron*, 1920, p. 430. C. Griffin & Co., London.

which are subjected to atmospheric influences, and, owing to its electropositive character, zinc affords very efficient protection.* This extremely important process of galvanisation by hot dipping also suffers from the defect inherent in the tinning process, that by its aid zinc coatings cannot be applied to very large bodies or to steelwork construction *in situ.* The process is applied mainly to the coating of sheet metal and not extensively to very large solid castings or massive bodies on account of the difficulty which arises by removal of much heat from the molten metal bath.

The Galvanising of Sheets.†—Presuming that the sheets are delivered to the pickling department properly annealed, the practice is to pickle in a solution of sulphuric acid and water, 10 to 15 per cent. acid. There are many methods of pickling. The old hand-operated method required two long and narrow tanks with a depth of about 6 to 8 inches greater than the widest sheet to be treated. These tanks in England and Wales were usually constructed of stone slabs 4 inches thick, rebated at the joints, and made acid and water-tight with sulphur. The sheets were dropped into the tanks on edge in batches of about one ton. The picklers stood on a platform and pushed the sheets backwards and forward by means of long steel rods having chisel points. To ascertain if the process had been carried far enough, one or two sheets from different parts of the pack were lifted out and examined. This method required a considerable amount of skill and experience, was at the best uncertain, and was particularly unhealthy for workmen. It is now, happily, practically obsolete.

There are several methods of mechanically pickling sheets commercially more or less successful, and all a very distinct advance on the hand method. In all of these the sheets are packed on edge in acid-proof crates, which have vertical pins at intervals to prevent the mass of sheets too closely adhering together.

The principal types used are :—(1) the oscillator plunger type, in which the acid is agitated around and between the sheets, which remain quiescent ; and (2) the Mesta type, in which the sheets are plunged up and down in the acid.

The tanks are usually made of pitch or yellow pine. For the oscillator or plunger type the tanks are made long enough to accommodate the longest sheets to be pickled with about 1 foot of end clearance, and are about 5 feet wide. If the plunger is actuated on the side, a separate partition is arranged between the sheets and the plunger, but the partition does not extend the whole depth of the tank. The plunger in this type is formed of pine about 12 inches thick and 4 feet deep, with about 26-inch stroke. The end type of plunger is exactly similar, but is less in size, being placed at the end of the tank, crosswise. Of these two, the side plunger gives the better results.

An exactly similar tank with plunger is necessary in both cases for rinsing the acid off the sheets after they are sufficiently pickled.

The Mesta type consists of a steam cylinder carrying the acid-proof crates. There are three tanks placed at right angles to each other on three of the four quadrants of a circle. Two of these tanks contain acid solutions and the third water. It is possible to utilise the waste strong solution to

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* Turner, T. : *ibid.*, p. 130.

† Poppleton, C. F. : *Met. Ind.*, 1918, **13**, 238.

provide the strength for the second or weak acid bath, as of necessity a certain amount of the strong solution adheres to the sheets and crates. This machine enables the use of two pickling baths, a very desirable feature, without extra labour or floor space, and the rinse water is not charged with acid as rapidly as is the case with the single pickle tank of the plunger system. Further, steam is required to heat up the acid solution, and the exhaust steam from the Mesta machine can be used for this purpose.

After inspection the sheets are placed in a storage tank and kept covered with water. It is very important that the acid-soaked sheet should be exposed to the air for the shortest possible time, as oxidation takes place rapidly on the pickled surface. The finished work will be much improved by allowing the sheets to remain in the storage tank for at least seventy-two hours; in fact, a week is not too long. Over-pickled sheets, which always produce "grey" galvanised sheets (that is, small, almost imperceptible, spangles), may be "brought back" to a certain extent by a long immersion in water.

From the storage tank the sheets are taken, about twenty or thirty at a time, into a solution tank, which contains a weak solution of acid and water (about ½ per cent. to 1 per cent. hydrochloric), and from this tank are immediately dipped. The surface of the zinc bath is covered with ammonium chloride with some tallow. Dipping or coating still retains its old name, albeit to-day the sheets are coated by machinery.

The process is always fettered to one spot by the need for a large tank of molten metal and other stationary plant. In galvanising, an iron-zinc compound is formed at the junction of the iron and the zinc, and this compound appears to be less anodic towards iron than is zinc, and it therefore provides less protection. The microstructure consists of two or three distinct layers. Next to the base metal there is a layer of $FeZn_3$, while the outer layer is mainly zinc containing some iron in solid solution, and there may be an intermediate layer of $FeZn_7$. The iron-zinc compounds are more brittle than zinc and they cause the coating to crack and peel when it is bent. It is worth pointing out, therefore, that corrosion tests of zinc-sprayed iron and galvanised iron have shown the sprayed zinc to be a better protection against corrosion. Indeed, zinc-sprayed iron appears to be about as effective as solid zinc in its resistance to the atmospheric influences. For cast iron and massive articles the metal-spray process of zincing appears to have a big future and to be in many ways superior to galvanising. In general, spraying will be used for heavy articles, and galvanising for many types of routine work upon thin sections.

Sherardising.—Sherardising is a process whereby articles of iron and steel are heated in a rumbling barrel in contact with zinc powder and zinc oxide. The zinc diffuses into the objects undergoing treatment and forms a hard surface layer of rust-resisting iron-zinc alloy. A process similar to this was practised many centuries ago, although for another purpose. At that time it was known that if copper tools and vessels were placed in the ground in certain localities and kept hot for a time by building a fire over the place, then on removal, it was seen that the copper had assumed a light yellow colour and had become harder and more durable. This process, now known to be due to the cementation of copper by the zinc of calamine or other readily reducible zinc ores, was virtually a dry galvanising process.

Also, in Greek history, according to Aristotle, the "bleaching of copper" was accomplished by the same method. The sherardising process was discovered by accident. Commander H. V. Simpson of the British Navy was experimenting upon a method for case-hardening armour plates which would not infringe the Harvey patents then being used by nearly all governments for rendering armour plate as shell-proof as possible.

These experiments were being tried out in the laboratory of Sherard Cowper-Coles of London. A package of zinc dust had been sent to Mr. Cowper-Coles to determine whether it could be used in making an electrolyte for zinc plating. In the course of their experiments they placed a piece of steel in this zinc dust in a case-hardening oven and heated it up to see if it would have any hardening effect on the metal. When taken out it was covered with a silvery coating of zinc, and on examination under the microscope they found it had penetrated and alloyed with the body of the metal.*

The term "sherardising" generally brings to mind the idea of zincing iron, and one overlooks the fact that the process is not only applied to iron, and also is not limited to the use of zinc. Nevertheless its greatest importance is in the field of zincing iron, so that this limitation in the use of the expression has some truth in it. The process is carried out as follows: Iron articles of any desired shape which have been cleaned in the ordinary manner, by trichlorethylene, pickling or sand blasting, are packed into a closed metallic container with zinc dust together with fine silver sand and heated as far as possible in the absence of air.

A dull red heat was thought to be necessary, but the usual temperature is 370-400° C. After this treatment has continued for ½ to 2 hours, the container is cooled down, opened, and the iron articles are removed; they are found to be covered with a smooth, tough, adherent zinc coating, which is comparatively homogeneous, free from large crystals, and has a silver-grey colour. The structure consists of a layer having a fissured appearance, with an average iron content of 8 to 10 per cent.

The zinc dust of commerce contains 5 to 8 per cent. of zinc oxide, which does not melt at the temperature of the operation. In the absence of such oxide care must be taken to prevent the melting of the whole mass by the addition of sand, carbon, powdered marble, or similar neutral materials, which separate the zinc particles and hinder them from clotting together. The iron is thus only in contact with the zinc fume which is produced in the process.

It is certain that the iron is not in a molten bath, but in a powdery dry mass, whose zinc fumes it absorbs to a certain extent.

A patent exists for the use of antimony, tin, cadmium, and bismuth in a similar manner, and other metals besides iron may be coated.

It is worth mentioning here that there are also other processes of metallisation depending upon metal vapours and producing somewhat similar coatings to those found upon sherardised articles.

Sherardising gives excellent results upon small articles, and with slight modifications is being used successfully in many countries. The expense of the plant is not great and the control is simple. However, only metal

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* Flanders, W.T.: *Galvanising and Tinning*, 1922, p. 227. U.P.C. Book Co., Inc., New York.

can be coated by this process, and only such shapes of article as are sturdy enough to withstand treatment in a rumbling barrel. Furthermore, the process is naturally limited to stationary plant, and can only treat comparatively small articles.

Sherardising and the barrel method of automatic metal spraying described in Chapter III compete upon almost equal terms, but whereas the spray process has other possibilities, sherardising must of necessity be limited to hot rumbling-barrel work.

Calorising.—The problem of the oxidation of metal parts when subjected to the action of intense heat is of great importance; there is hardly any industrial plant which does not experience some oxidation trouble from high temperature, and the loss which this entails in labour, time, and material, is really enormous.

The following is a list of processes used for the protection of iron products with aluminium coatings :—

1. Iron-aluminium alloying (10 per cent. Al).
2. Calorising.
3. Aliting.
4. Treatment with aluminium chloride vapour.
5. Aluminising or alumetising.
6. Aluminium powder paint coatings.
7. Galvanic aluminium deposits.
8. Immersion processes :
    the Dellgren, C. Fink, Nilsson and other processes.
9. The hot- or cold-rolled-on coatings.

Experiments have shown that in iron-aluminium alloys scaling at temperatures above 900° C. becomes practically negligible with about 9·5 per cent. aluminium, at which stage the alloys become covered with a reddish or white oxide film which inhibits further oxidation.

The calorising process, of which a number of variants have been patented, consists in heating the iron articles in contact with a mixture containing aluminium powder and ammonium chloride, together with alumina, graphite or, in some cases, zinc.

The process of calorising was invented by T. Van Aller in 1911, and was developed by the General Electric Company of Schenectady, U.S.A. Since its inception, however, the process has been the subject of extensive experimental work, and, as practised to-day, is a modification and improvement on Van Aller's original invention.

Broadly speaking, the process of calorising consists in the formation of a surface alloy of aluminium on ferrous and non-ferrous metals, and is achieved by placing the articles to be treated in an air-tight retort, partly filled with the calorising mixture (which consists of finely divided metallic aluminium suspended in aluminium oxide), and subjecting it to a high temperature for several hours. During the process a continuous current of hydrogen is passed through the retort to ensure an inert atmosphere. Before being placed in the retort the articles are required to be thoroughly cleaned and to have a surface free from grease, scale, or other foreign matter, this being effected either by sand blasting or pickling. The treatment, conducted at high temperature, so thoroughly infuses aluminium into the exposed portions of the metal being treated as to form a homogeneous alloy to a certain depth. This depth ranges from a few thousandths of an inch to the permeation of the entire mass, and is governed by varying the duration of the treatment and the composition of the mixture.

The limiting temperature at which calorised articles will resist oxidation is governed by the nature of the alloy formed and the service to which it is subjected. Generally speaking, this limit varies from 900 to 1000° C.; although it is possible by a total impregnation of the metal, giving an aluminium content of about 15 per cent., to render the article resistant practically up to its melting-point.

Calorising can be applied to ferrous and non-ferrous metals—cast iron, wrought iron, malleable iron, steel, nickel, nickel steel, copper, and brass; and in all instances where metals suffer from the ravages of heat oxidation, the wasting effect of some forms of corrosion and the deleterious effect of certain gases, calorising can be used with advantage. The results obtained with certain metals are better than with others; for instance, greater protection will be afforded to mild steel articles, particularly those which have been mechanically treated by processes such as pressing, rolling, spinning, etc., than to ordinary castings.

A G.E.C. patent specifies a mixture of 20 per cent. aluminium powder, 23 per cent. ammonium chloride and 7 per cent. zinc. The iron articles are heated with this mixture in air-tight rotating drums at 450° C., then removed and heated for another 15-20 minutes at 700-800° C., to complete the diffusion. Instead of zinc one can use graphite, the composition of the mixture being 60 per cent. aluminium powder, 30 per cent. graphite and 10 per cent. ammonium chloride, the reaction temperature being raised from 450° to 700° C. E. D. Martin suggested the use of a mixture of 50 per cent. aluminium powder, 45 per cent. alumina and 5 per cent. ammonium chloride, the articles being treated at a temperature of 810-830° C. Calorising treatment increased the life of iron and steel articles from five- to six-fold at temperatures of 800-1000° C.

The aliting treatment, used particularly by Krupp, resembles the calorising treatment, but instead of pure aluminium powder, a powdered 50 per cent. aluminium-iron alloy is used, mixed with 5 per cent. ammonium chloride. The advantage of this mixture is that it does not require the use of rotating containers and of a hydrogen atmosphere. The articles are cemented at 900-1200° C. for periods up to 8 hours, both the time and temperature depending upon the subsequent service conditions for which the articles are intended. The coating is formed by an iron-aluminium alloy containing 10-15 per cent. aluminium and its mechanical properties are better than those of the coating obtained by the calorising treatment.

The aluminium chloride process has been developed by E. D. Martin and consists in forming a thin aluminium coating on iron by treating it with aluminium chloride vapour at 900-1000° C. The aluminium chloride is produced separately by heating a mixture of 45 per cent. aluminium powder, 45 per cent. alumina and 10 per cent. ammonium chloride to 600° C. The process is not used commercially.

The aluminising or alumetising process consists in obtaining an aluminium coating by the Schoop spraying process. The comparatively porous coating obtained is then heat-treated, which brings about a diffusion of the aluminium into the iron. An oxidation of the aluminium deposit during the heat-treatment occurs and the deposit is usually coated with a type of flux. The diffusion of the iron into the aluminium may be prevented by the use of an aluminium-high melting-point metal alloy in which the solubility of the iron is low.

The aluminising process is also used to prevent chromium steels during heating to forging temperature from taking up carbon, which would lead to brittleness.

For aluminium paint coatings, a colophonium-pitch mixture is used as a vehicle for aluminium powder. By heating the articles to 700-800° C., a diffusion of the aluminium into the surface of the iron is said to be effected.

Galvanic plating methods for aluminium from non-aqueous solutions have been developed by Russian research workers, using molten salt mixtures containing aluminium and alkali chlorides.

A large number of variations of the immersion process of aluminising have been developed and patented. The essential steps of the process consist of preparing the surface of the iron either by heating in a reducing atmosphere or by using a liquid or flux treatment.

The tinning or galvanising of the iron surface prior to aluminising has also been suggested. In immersing the iron in the molten aluminium, care has to be taken to prevent aluminium oxide films being trapped between the aluminium and the iron surface.

In the Dellgren immersion process for strip and wire, the iron passes through a molten flux consisting of zinc chloride and ammonium chloride and then passes through the molten aluminium bath. The molten aluminium is kept in a cylindrical container open at the bottom and immersed in molten lead. The iron wire or strip enters the aluminium from below at the lead-aluminium junction, where the formation of aluminium oxide films is thus avoided. The whole apparatus is air-tight and filled with a reducing atmosphere.

In the Fink process for wire, the wire is first passed through dilute hydrochloric acid, then through a furnace where it is heated to 600° C. and immediately afterwards passed through boric acid ; it is then passed through a second furnace in which it is heated to 900-1000° in an atmosphere of hydrogen. It then passes through the bath of molten aluminium and finally, after passing through a die, is rolled up on a drum. The temperature of the aluminium is from 700-720° C., and the wire or strip is passed through it at the rate of 2-5 m./min.

In the Nilsson process the surface of the iron articles is cleaned by pickling in a molten flux consisting of 10 per cent. cryolite, 20 per cent. zinc chloride, 30 per cent. sodium chloride and 40 per cent. calcium chloride.

In all immersion processes it is important to adjust the conditions of treatment in the molten aluminium in such a way as to avoid, if possible, or to reduce the formation of, a layer of $FeAl_3$, which is brittle and impairs the adhesion of the aluminium coating.

Finally, there are a number of processes for rolling a surface layer of aluminium on iron or steel sheet or strip. This may be done either by hot or cold rolling, the rolling usually being followed by heating of the plated product to effect a certain amount of mutual diffusion of the two metals.

If now we consider the field of rust-protective coatings as a whole with the various processes which differ fundamentally from one another, and try to put them all in parallel with the metal-spray process, it is immediately apparent that in certain cases competition must develop. Undoubtedly, however, galvanising and tinning will remain the principal methods of rust-proofing thin sections, sheets, and wire. For the manipulation of smaller pieces, however, which are not so easily dipped in baths or embedded in metallic dust, competition has already developed, and the most economical process will finally exclude the others.

Furthermore, if one also considers the extensive field of rust protection of *large* articles (such as girders, and parts of buildings which cannot be impregnated with zinc fumes in a chamber, or of finished constructions, bridges, cranes, and towers), and also bears in mind the renewal of damaged coatings on iron constructions, it is at once apparent that here the metal-spray process is superior in many respects, since not one of the older processes described can compete with it from the point of view of application to articles *in situ*. At the present time one can only resort to painting, which is cheap in first cost, but the advantage of the much greater resistance and wearing qualities of sprayed metal coatings cannot be ignored.

Electroplating.—Electroplating developed from the observations which Galvani made about 1789. Volta had obtained electricity, some ten years later, from a practical application of the facts observed. Cruikshank and Wollaston, using Volta's " pile " as a source of current, effected the first dissociation of metallic salt solutions and precipitated coherent copper upon silver. In 1805 Brugnatelli first achieved the real " galvanic gilding " of silver coins. The intentional copying of metal originals in this manner, electrotyping, dates from the year 1839 ; in this year Jacobi published reports about his experiments in Russia to produce stereotype plates by the aid of the electric current.

Thus practical electroplating was created, and it is surprising to observe how quickly this new process, which filled a long-felt want, was developed. In incredibly rapid succession inventions and processes appeared which improved upon the original both technically and economically.

Murray succeeded in manufacturing plated reproductions on non-conducting negatives, such as plaster of Paris, by covering the mould with graphite and thus making it conducting. In this manner the framework for the whole process was set up, and the important inventions which have since been made are only building-stones fitted into the structure already raised. The practical perfection and the removal of minor difficulties proceeded, but produced no fundamental change in the process. The basis of the whole industry, contact electricity or galvanic current, was in the meantime replaced by dynamo-electricity, which was much more economical, reliable and serviceable.

One distinguishes between electroplating and electrotyping, *i.e.* between that manner of carrying out the electroplating process which provides objects with firmly adherent coatings, in which, therefore, the chief condition is that the coating shall be inseparable from the foundation material, and that method which produces metallic bodies capable of being taken off from their base and strong enough in themselves to be so used.

The technical operation is, apart from the preparation of the foundation material, the same in both cases. Electroplating solves the problem of covering a metallic surface with a firmly adherent metallic coating by the aid of the electric current. In all cases where the adhesion of the coating is necessary, for instance, in the silvering of tableware, the surface of the metal to be covered must be absolutely clean, since the slightest amount of metallic oxide, grease, or other impurities hinders complete union of the two metals and makes impossible the production of a coherent coating.

This important question of cleaning or pickling has caused much trouble among platers, and the literature of the subject contains hundreds of special processes for cleansing the various metals. The cleaning process may be of a mechanical character (in which the articles are scratch-brushed, rubbed, polished, and so on) or of a chemical nature. The latter usually consists of the application of a grease solvent (*e.g.* trichlorethylene) and a dilute mineral acid by which oxides are removed. The greatest care must be taken in all these processes of cleaning, as they constitute the main factor determining the quality of the plating. Frequently a search has been made for the causes of failure by altering the current conditions or the composition of the bath, while insufficient cleaning or subsequent dirtying was really to blame.

While the chief purpose of electroplating is to apply an inseparable metallic coating, this can only be accomplished on surfaces which consist of metal; electrotyping, on the other hand, can be carried out on any desired surface so long as it is rendered electrically conducting by a thin layer of material which need not be firmly adherent. If the bodies consist of non-conducting materials such as plaster of Paris, clay, or rubber, they are made conducting by rubbing in graphite or by bronzing, or by some such similar treatment. If they are metallic they must be covered with a thin insulating layer, otherwise the coating would adhere. Here the difficulties of electroplating indicate the procedure necessary for electrotyping; as already mentioned, the least trace of grease prevents the proper union of the metallic deposit with the foundation material. It is therefore only necessary to cover over the foundation with a uniform layer of grease or oil where the union is to be only temporary. This method serves well for large objects with rough surfaces, but with fine models having only very small differences in level from one part to another there is difficulty. For example, with copper printing blocks, whose delicate impressions would be filled with the grease, the electric current is generally used to produce the insulating layer by electrodepositing a very thin coat of silver and changing this with iodine or H_2S water into silver iodide or sulphide. If even this layer is too thick, a silver solution is applied and subsequently reduced to an excessively thin metal layer by chemical means, and this can be further treated as described above.

If now we compare the advantages and disadvantages of electroplating and the metal-spray process, both relative to the operation of the two processes and to their applications and the properties of their products, we must first say that electroplating produces metallic layers which are in no wise inferior to the sprayed coatings. The metal-spray process to-day gives products which are incomparably better than those obtained when the process was first introduced, and gives also a metallic coating which, with regard to strength and resistance to fracture, approximates to cast metal. The same may certainly be said for the metallic products of the electroplating process; some exceptions in special fields exist, but there are no considerable differences in this direction.

On the other hand, the metal-spray process represents in comparison to electroplating a tremendous advance with regard to speed of working, for any one article. Since many articles may be plated at the same time, the times required by the two processes may not be so dissimilar on routine work.

This advantage of higher speed must be placed side by side with the equally great advantage that all metals used in industry may be sprayed, whereas plating is possible with only a limited number of metals. It is true that to-day we have reliable electrolytic lead baths which are worked with a current density of 15 amperes, and which give quite solid deposits, adherent, and capable of competing with the products of the more expensive process of lead burning. The industries which use apparatus and containers of large size covered with lead sheet have used this new process for some time. The same is the case with iron; we are, for example, to-day in a position to manufacture by electrolytic means iron tubes similar to steel, and whose quality will stand any comparison.

The electrodeposition of aluminium is, however, still a problem for future generations, and even the problem of coating aluminium electrolytically with other metals has waited a long time for solution, and to-day remains still unsolved for many metals, principally because of the great difficulty of obtaining an absolutely clean aluminium surface.

The metal-spray process, on the other hand, encounters no difficulty of any kind with regard to working with aluminium; on the contrary, this metal adapts itself, on account of its comparatively low melting-point, particularly well for the process.

On the other hand, the electrolytic method has many advantages which would retain several immense fields of application even if the metal-spraying process continues to accomplish what it promises to-day. Thus, for example, the electrolytic deposition of alloys is a problem whose solution may be regarded in many cases as completely solved. The electroplating of brass has for long been an everyday business, and for its accomplishment there are a number of methods which may be followed without difficulty. Such baths are generally made up from double salts containing the single metals in the correct proportions for the electrolytic dissociation and deposition. Alloys of more than two constituents may also be deposited electrolytically.

The electrolytic coating of wires, tapes, and sheets keeps a great industry busy, and such products are rolled off from the supply reel at a speed proportional to the thickness of the desired coating; cleansed, pickled, drawn through electrolytic baths, washed, dried, and wound up—completely coated, by the mile.

Also the coating of the interior and exterior of tubes of small cross-section is accomplished by this electroplating method. Several extremely practical devices are employed in these operations, in which long tubes are carried on guides or transport wheels and zinced inside and outside at the same time, using inside anodes extending throughout the whole length of the tube. In such work the metal-spray process can hardly be made competitive with the electrolytic process.

Many of the troubles encountered in electroplated articles are due to the need for pickling. Acids or acid salts are retained in the pores of the metal, and later spot or otherwise spoil the polished surface. In some cases the blemish only appears after months of use. In that pickling does not precede spraying the sprayed article is less liable to this trouble.

Chemical Metallisation Processes.—The basis of this class of processes is the reduction of pure metals by chemical means from their salts or compounds, either in solution or in the dry state.

A very interesting example of the latter case is provided by the method of coppering carbon brushes for dynamos and electric motors, by a process patented by Siemens Brothers.

The coppering had previously been accomplished electrolytically, but this method suffered from the decided disadvantage that the electrolyte necessarily absorbed by the carbon both hindered satisfactory adhesion and, later, when the article was dried, the salts crystallising out spoilt the copper coating. Obviously metal spraying would be far superior to that for this particular application, but its use would be in competition with the Siemens process referred to above.

According to this process, the carbon body to be coated is embedded in a dry oxygen compound of the metal, for example, copper oxide or copper hammer scale or some such substance, and is heated to about 300° or 400° C. The similarity to the sherardising process is obvious, but the latter can only be carried out on metal and depends upon sublimation or diffusion, whereas with the Siemens process one cannot assume that at such comparatively low temperature copper vapour is produced in any quantity worth speaking of. The process is probably, therefore, of a purely chemical nature, and consists of a reduction of copper oxide by carbon. The inventor admits that the chemical reactions which occur are difficult to follow, but the fact is that a firmly adhering and completely uniform copper coat is produced. The further pursuit of this idea of reducing metallic oxides by carbon led to the establishment of a process for metallising bodies of any desired material after their surface had been covered with an adherent carbon covering. The bodies to be metallised are first painted with solutions of such materials as sugar or glue, which carbonise at the necessary temperature. When the carbon coating has been formed in this manner, the bodies are embedded in the metallic compound and heated. In this manner all materials which can be heated to 400° C. without danger, such as porcelain clay, most artistic stones and such objects, may be provided with a metallic coating.

This is a dry method and an exception among the chemical processes, the majority of which are based on the reduction of solutions of metallic salts or compounds from which metal is precipitated, and are, therefore, wet processes. Such fundamentally similar processes, which differ only in the manner of their accomplishment and whose number is naturally very great considering the possibilities in chemistry, are not really in competition with the many electrochemical processes, because they fill up the gaps left by such processes in permitting the metallisation of non-metallic surfaces.

An example of such process is that in which a silver solution is applied to the article and metallic silver is precipitated upon it by means of reducing agents. This reaction occurs with results differing according to the chemicals used to effect reduction. The precipitate can be more or less powdery, grain-like, or smooth and coherent. The conditions producing these results and the influence of various chemicals have been studied most carefully in the manufacture of silver mirrors. The best-known experts, among them Justus von Liebig, have striven to obtain a thin and continuous silver coating, and as a result the methods used to-day undoubtedly stand at a height which can scarcely be surpassed. Silver nitrate in water is used, the solution being made slightly alkaline by ammonia or by calcium hydroxide, and various reducing agents have been employed with much the same success.

Naturally the same result can be obtained under the proper conditions with other metals, such as gold, platinum, and copper, but the chief use of this process is in the manufacture of mirrors. However, porous materials, lace, fabrics, and similar products which have a more or less matte appearance, may also be treated by this process.

With opaque substances such as porcelain, the process is often used merely to obtain a metallic foundation upon which thicker metallic layers may be subsequently electrically deposited. Fabrics and lace, on the other hand, which are first saturated with a solution of the metal and then metallised by reduction, are final market products. They look well and have considerable value as substitutes for those goods which are woven with metal threads.

Whether metal spraying will succeed in replacing many of these chemical metallising processes is doubtful, since the deposits obtained by reduction are extremely thin and hold intimately together, properties of the greatest importance; it seems, therefore, that they can scarcely be replaced. On the other hand, one must bear in mind that sprayed coatings are more resistant to mechanical attack and give better results on the surface of porous materials of slight hardness—such as wood, cork, asbestos, slate, and artificial stone materials—than do chemical solutions which entirely soak through these bodies; this circumstance will make the use of the spraying process possible in many cases.

We now come to the consideration of some miscellaneous metallisation processes. First may be mentioned a chemical process which is limited to the treatment of porous ceramic products, and consists of applying an alkaline solution of silicates to the porous surface and combining this with a solution of silver chloride. To improve the union of the two solutions with the foundation material ammonium fluoride is added, which acts as an "etchant" upon the surface, so that the silver combines very firmly with the ceramic surface as soon as it is precipitated by reduction.

Another interesting special process which was protected several years ago by the A.E.G. aims to provide easily oxidisable metals such as aluminium with a coating of tin, for example, in order to protect them against chemical agencies or to prepare them for soldering. Such metals are always covered with an oxide coating, even though it be very thin, and if one removes this skin by mechanical means, for example by scratch-brushing, and applies a molten coating metal, even the short period which elapses between the two treatments is time enough to allow the formation of a new oxide film which is sufficient to hinder the absolute adhesion of the coating metal. It was therefore proposed to scratch-brush the aluminium beneath the surface of the molten coating bath; this is, however, easier said than done. The best results were obtained as follows:

The heated metal surface was rubbed with felt or asbestos and a mixture of fine-grained abrasive materials—such as emery, sand, or glass powder—while the molten tin was rubbed in. The coating was said to hold well, and especially thorough cleaning of the aluminium surface was not necessary. Naturally the thickness of the coating in the A.E.G. process is much more limited than in the spraying process.

In connection with the discussion of the sherardising process, reference was made to a process long known in principle, which consists in the use of metallic vapour for metallising. The manufacture of coatings from metallic vapour which streams under normal pressure on to the surface to be covered is therefore nothing new. Two inventors have proceeded in this way, and have evolved processes which are remarkable because their operation is possible not only on metallic foundations but on all materials which can resist a high temperature. Both the inventors, Arndt and Pringsheim, allow a metallic vapour produced *in vacuo* to solidify as a coherent foil or firmly adherent coating on any desired surface. Arndt uses an electric arc struck between electrodes in a vacuum, the anode consisting of the coating metal. The metal vaporises and is deposited on to the articles, which are placed inside the evacuated chamber.

According to the duration of the operation either transparent films or definite sheets are formed up to a thickness of several millimetres.

The Pringsheim process is more specialised in its aim, but more general in its application; in this, also, metals are vaporised *in vacuo*, but any source of heat may be used so long as its thermal power suffices to vaporise the coating metal. The purpose of the process is solely to provide metallic surfaces with a high mirror lustre, primarily for optical mirrors. This vaporising, effected by purely thermal means in a vacuum, gives, on glass or metal, coatings which possess exactly the same optical smoothness as the foundation material itself, and therefore give just as good a mirror as a highly polished glass surface. From the statements of the inventor it appears that according to this method he could prepare optically perfect mirrors from such easily oxidisable metals as aluminium and even calcium.

A process worked out by Stolle has not yet realised practical success, but it appears remarkable enough to be here mentioned in that its fundamental idea combines the principles of the vaporisation and metal-spray processes. By combining both ideas Stolle arrived at the conception of projecting pure metallic vapour by gas pressure on to the article to be covered. This process is still in the experimental stage.

The last to be considered in this survey of metallisation processes may be regarded as the invention of R. Rafn, and though patented in 1913 the fundamental principle was actually discovered in 1877. The basis of the process was the observation that the negative electrode in a Geissler tube, traversed by high-tension electricity, emits metallic vapour and deposits this upon the walls of the tube. The effect is particularly noticeable in the case of metals of high specific gravity. Wright in 1877 first thought of the practical utility of this phenomenon, and prepared transparent mirrors, which in spite of their extreme thinness were completely homogeneous. Eighteen years later Boas was granted a German patent for the preparation of mirrors by this process. The invention related to the special means of concentrating the metal particles, which were scattered in all directions, into one definite direction. The metal strikes on to the wall of the vessel in complete purity and absolute solidity, producing a mirror of so high a lustre as can be produced by no other means. Since the molecules settle equally beside and above one another and no fine scratch-producing polishing material need be used, as in the usual silver mirror manufacture, the reflective powers are thus the highest possible for the metal in question. The Rafn process is similar fundamentally to Boas' process. Both of these methods work in the cold or at a slightly elevated temperature ; thus Rafn's process may be used like the metal-spray process on articles which are sensitive to heat, metallisation of which was previously impossible.

Flexible or fibrous materials are just as elastic after metallisation in this way as before it. Ostrich feathers, gilded by means of this process, are as pleasing as fine filigree work. In Rafn's process metal spraying possesses, therefore, a competitor having the advantage of the relatively low temperature of the deposited metal. A point which was of great value in the introduction of the metal-spray process.

These electrical methods permit metallisation of heat-sensitive materials without any previous preparation, but are limited in sphere because the electrical projection only takes place with metals of high specific gravity. The use of aluminium is thus excluded from the electrical method. With pure, heavy metals the results are excellent, and whether the process, which has not yet been applied practically, will eventually be able to compete with the other processes, it is not yet possible to say. That will depend less upon technical than economic grounds.

Many other processes of metallisation or modifications of those described are now in existence. It is thought, however, that sufficient has been here written to enable the reader to see the width of the subject and to fit the new metal-spray process into its correct position relative to other available methods of operation.

CHAPTER VII.

APPLICATIONS OF THE METAL SPRAYING PROCESS.

ALTHOUGH comparatively young, the metal spraying process has already found so many commercial and technical applications that considerable difficulty has been experienced in dealing adequately with the subject-matter for this important chapter. The practice of spraying in the different countries is both extensive and diverse. Many hundreds of licences have been issued to individual manufacturing concerns enabling them to use the process in their own factories.

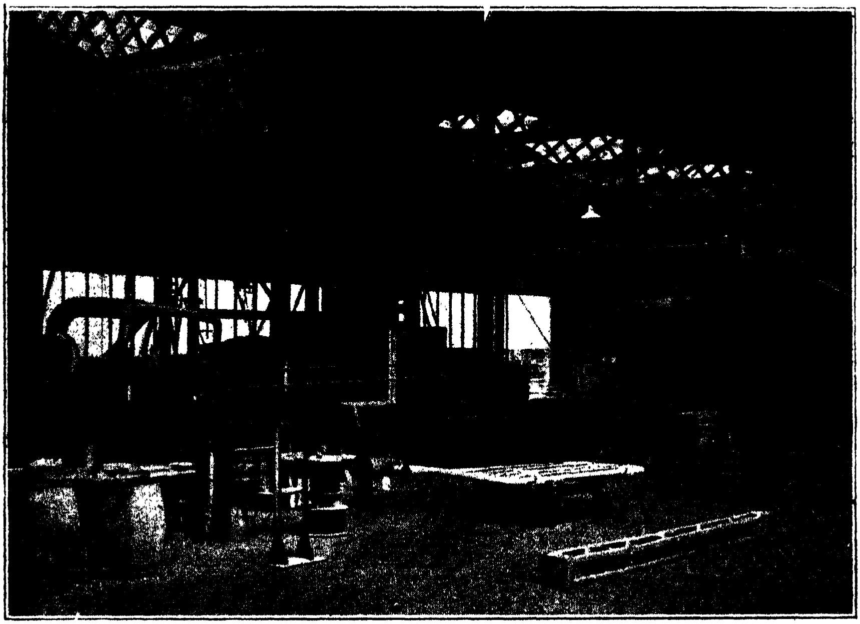

FIG. 174.—Metal-spraying Works established in 1924 at Dudley, England.

The process has been developed in England energetically only since the War, and the works illustrated in fig. 174 was only completed in 1924.

Rust Proofing of Constructional Work.—An important and useful field of application for the metal-spray process is in the rust protection of iron constructions. Here zinc coatings are generally the most satisfactory. It is at once obvious, from a glance at the patent files showing so many methods for rust prevention, that this subject is alike one of extreme difficulty and of great importance. The oxidation of iron, forming iron oxide, occurs, as is well known, whenever iron is exposed to air and moisture, and the object of rust preventive coatings is to protect the iron from contact with these substances.

The usual method of attack upon this problem has been the application of the so-called rust-preventive paint, which requires renewal after a few years, its durability depending upon the atmospheric and other influences to which the coating is exposed. This constant replacement of protective coatings upon iron and steel outdoor constructions is very costly, and means have everywhere been sought to find a more lasting covering. Experiment has shown that really durable coatings are only obtainable by the use of aluminium, lead, or zinc ; the last metal is most generally used as a rust preventive, and is applied by either the galvanising, electrolytic, or sherardising processes. With these, however, the objects to be coated are limited in size to the dimensions of the baths or vats, and also the comparatively high temperature necessary for sherardising may be disadvantageous.

The metal-spray process, on the other hand, is not limited in these directions, and may with equal facility be applied to the coating of the smallest of machine parts or to the largest conceivable constructions, such as bridges, cranes and railway stations. For instance, steel window frames are difficult to galvanise because of size and distortion. Even if the material is treated with zinc before fabrication, spraying is essential at the corners where welds are made. In many cases a 2/1000 inch coating of zinc suffices to prevent corrosion in those places where condensed water finds its way between small crevices, and the matte surface provides a good anchorage for the paint which is usually necessary for appearance sake.

Fig. 175 shows a molten metal pistol in use and the melting furnace is seen in the background.

Where conditions are more severe, and where articles have not to be painted afterwards, the zinc coating is increased in thickness, depending on the conditions of service. For ordinary atmospheric conditions a coating 4/1000 inch thick is usual on transmission pylons, bridges and general outdoor structures. The zincing of large constructions has sometimes been regarded as too expensive, but simple calculation shows that in the long run a protective coating of great durability is cheaper than a coating requiring constant renewal. Recently it has been suggested that a protective paint should be applied followed by a coat of zinc powder, blown on, and finally a second coat of paint.

The possibilities offered by the spray process are especially useful for finally assembled iron constructions, which may be zinc-coated by this process only quite easily and comparatively cheaply. An example of this kind of work is the large steel framework shown in fig. 176, which was zinc-coated.

The process is obviously excellently suited for spraying the huge girder-work masts used for modern wireless stations, and this has already been done in many cases upon the Continent.

The fact that the zinc applied by this process can cover all rivet heads, fill in small crannies, bridge over joins, and so produce a single metal envelope over the whole structure is a tremendous advantage.

Where the parts are very inaccessible, such as in the case of lighthouses at sea or the top of large girder masts, the point should not be overlooked that the zinc coating may be painted. Iron or steel thoroughly cleaned by sand blasting, sprayed with a good layer of zinc, and finally given a coat of paint, may be expected to outlast a generation without attention. Paint adheres excellently to the matte surface of sprayed metals and does not crack owing to the gradual contraction of the paint, which is usually to be seen on painted metal surfaces.

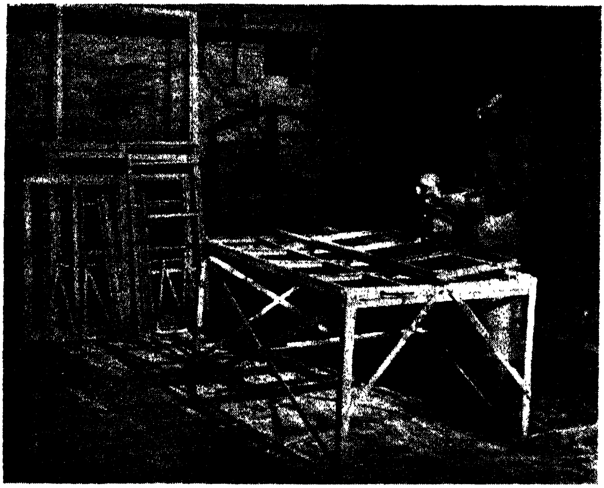

Fig. 175.—Metal Spraying Steel Window Frames (Molten metal process).

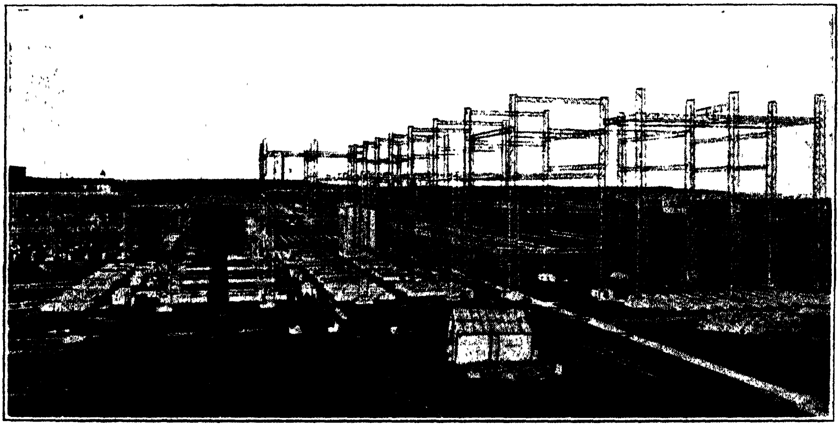

Fig. 176.—Constructional Work coated with Zinc by the Metal-spray Process.

For such iron constructions as require to come in contact with water, above all with sea water—such as landing-bridges, pontoons, and ships' plates—and also for iron constructions which suffer from exposure to nitrous fumes or even to the locomotive smoke which attacks railway stations and bridges so rapidly, sprayed zinc or lead is undoubtedly a valuable and economically sound covering. For coating railway bridges over which refrigeration cars and trucks dripping brine solution pass, spraying offers several advantages over painting. Each coating is immediately set, consequently any number of coats can be applied at one time. Paint remains tacky for several hours and if a train passes with water spraying from its tender, this may mix with the paint, destroying its bond and protective qualities. Such bridges may be sprayed with 2 oz. per sq. ft. of zinc on the upright surfaces subjected to atmospheric corrosion only and 6 oz. per sq. ft. on parts subjected to brine corrosion.

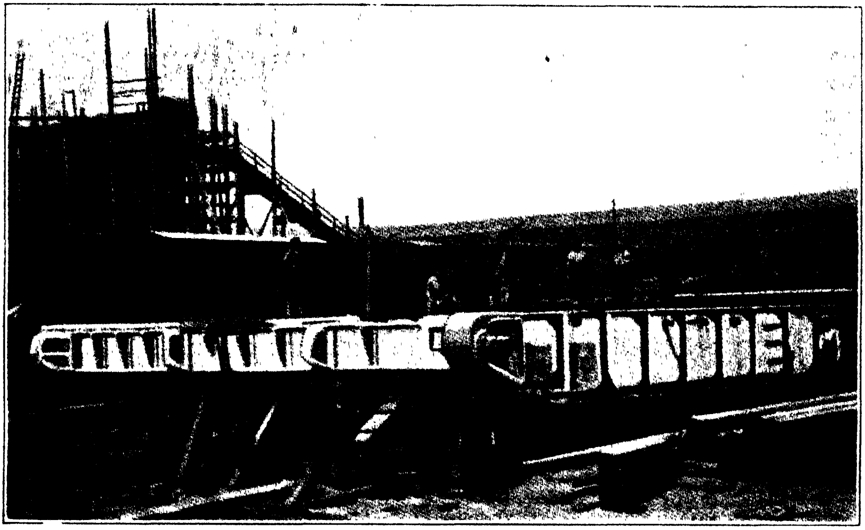

FIG. 177.—Zinc-spraying a Large Dock-gate.

The coating of a dock-gate with zinc is an obvious application of the process. This has been carried out already as shown in fig. 177. Similarly the Société de Métallisation in Paris has satisfactorily sprayed armour plates of nickel and chrome steels for the French Admiralty, both being types of steel upon which the other methods of applying corrosion preventive coatings entirely fail.

The new method of rust protection is of especial value for aircraft where a flying-machine may remain for days on end exposed to rain or snow because covering is not available. The rusting of iron and steel parts is in such cases extremely dangerous, since the comparatively thin parts, wires, and strips are much weakened. Electroplated or galvanised material has been used for these parts, and in France sherardising is also employed.

Spray zincing offers the advantage that it can be used on finally assembled apparatus, and weak spots may be subsequently zinced without dismantling; French aeroplane makers have used the process for several years. For such types of work the fact that the sprayed coating can be applied without affecting the previous heat-treatment of the part may be of considerable value.

For this reason the process was used abroad for coating the thin steel shrapnel helmets, which were used by all armies during the War, after the helmets had been toughened by heat-treatment.

General Engineering and Shipbuilding.—The rust protection of steel ships requires separate consideration, being a most important field for the use of this process. Painting with special ship's bottom paint is the general practice, but zincing is used to an increasing extent for naval purposes. Since the metal-spray process permits of the manufacture of zinc coatings which are no dearer than good paints, cost need not be considered. Further, since sprayed zinc coatings are little more difficult to apply than coats of paint, and since they can be applied just as well to the finished ship or to individual parts, no difficulties exist in this respect. The possibility of working on the finished object is of special advantage, since, even with a completely galvanised outer plating, there are always many unzinced places on which rusting first begins its attack. Sheared edges of plates which have been delivered zinced to the shipbuilding yard are unprotected; drilling rivet-holes and riveting damage the coating, and final bending or other working of the plates spoils the coherence of the protecting material. On places much bent, as at the bow, the attack by rust is first noticed. In all these cases the spray process permits protection of the weakened places, the coating of which can be strengthened as desired. Also it is possible to zinc-spray plates which have to be bent after the bending.

In the s.s. *Normandie* the entire ventilating system, refrigeration plant and the fire-proof bulk-heads were sprayed with zinc, but the largest area so treated on this ship was the three funnels. Many of the interior fittings on this liner were sprayed, such as the metal parts in the winter gardens, the lighting fittings in the bath-rooms and a large number of the bedsteads.

Ships' hulls may equally well be coated with copper, by this process if that is desired, as a preventive against the growth of barnacles and consequent frequent docking, bottom cleaning, and painting.

So successful has spraying of ships' galleys been that certain of the larger shipping concerns have recently arranged to have this carried out upon all of their ships. It is possible to do this when the ship is laid up at any port for a day or two. The same firm has coated numerous other internal parts of ships, both wooden and metallic partitions and bulkheads having been successfully treated. It has also been claimed that the Schori pistol can spray powdered bitumen on to oily surfaces, and this may have certain applications below decks.

Ships' propellers have been coated with zinc and lead with considerable success, the latter metal giving the most satisfactory results upon the usual type of slow-running mercantile marine propellers. In an exactly similar manner the spray process has been used upon water-turbine parts, as may be seen from fig. 178, which illustrates the spraying of a runner casting, an object which could scarcely have been metallised by any other process.

Many other similar parts have been treated, but it is obviously impossible to give a catalogue of such work in a book of this kind.

There are many other uses for this process in connection with mechanical engineering, hydraulic machinery, and steam raising and using plant.

In the spraying of pressings used in the production of wringers the mechanical handling of the parts to be sprayed enables girl labour to be employed for this mass production work.

The use of spraying for lining bearings has been patented (*e.g. Brit. Pat.* 410, 300) and is claimed to be successfully carried out, using Babbitt wire. In spraying a leaded bronze, the constituents of which have widely varying melting-points, two pistols could be used, one spraying copper and the other lead in the correct proportions, in order that the metals might be intimately and uniformly mixed throughout the bearing.

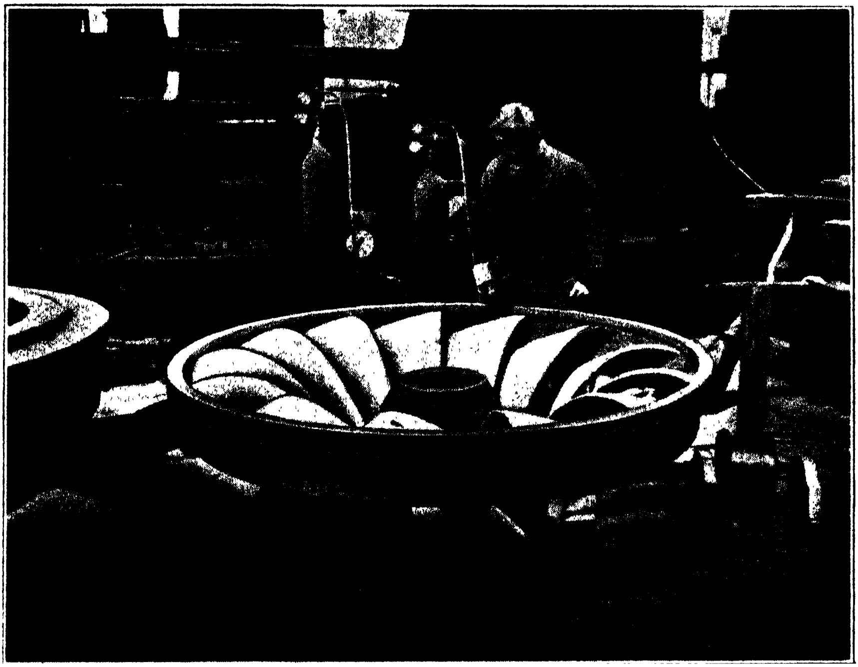

FIG. 178.—Metal-spraying of a Water-turbine Runner.

Another use for the process is illustrated in fig. 179, in which the spraying of a tramcar framework may be seen. In Switzerland, America and Germany, this process has been carried out on a fairly large scale, and it is obvious that it has much to recommend it, since the lower parts of a tramcar are of necessity exposed to the corrosive action of rain, wind and mud. That it is possible to coat over the finished framework after it has been riveted together is an obvious advantage. There is no reason why the use of the process for such purposes should not be extended, and why railway authorities should not adopt the practice of spraying the under-carriages of railway trucks and coaches.

As already mentioned, the metal-spraying process may be used for coating cast iron, so that castings may be metallised with any metal in almost as short a time as they may be painted. The tinning of castings has been a matter of some difficulty, and on account of the high price of tin the process has to be carried out with economy. The spray process offers the possibility of coating the inside only, or only such few parts as it is necessary to tin.

The metal-spray process may also be used in the foundry for taking impressions of patterns or for coating the usual wooden patterns with a metal coating whereby they are rendered more or less fireproof, wear longer, and separate more readily from the moulding sand. According to Roger, sand moulds of intricate castings which gave trouble through cracking due to uneven contraction, were sprayed with nickel at such places where it was necessary to delay cooling and to even out stresses. The sprayed layer not only acted as a chill, but also alloyed with the metal. In the manufacture of automobile engine manifolds, where a very clean core is demanded, aluminium-sprayed cores have been used with great success. Wiring has in many cases been eliminated owing to the support afforded by the sprayed coating. Plaster models for the Keller die-sinking machine can be coated with tin to prevent chipping off of the edges.

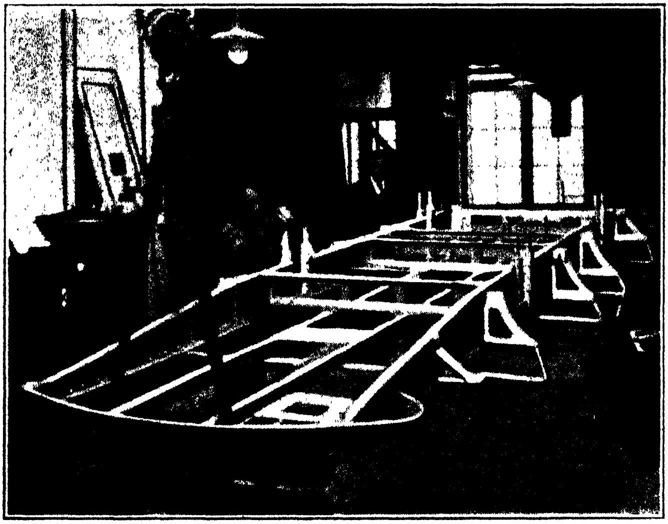

FIG. 179.—Zinc-spraying of a Tramcar Under-carriage.

The metal-spray process has been used for building up worn parts or defective castings, as shown in fig. 180, and for "welding" aluminium.

Erdmann* states that hydronalium (3-12 per cent. magnesium, 0·2-0·5 per cent. manganese and 0·2-1·0 per cent. silicon) can be sprayed and exhibits

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* W. Erdmann, *Aluminium*, June, 1937.

good wearing and corrosion-resisting qualities and also a high degree of polish. Electrolytic processes for light metal deposition are impossible, dipping processes for this purpose are not sufficiently developed as yet to yield commercially satisfactory results, but encouraging results have been obtained with spraying. Spraying the alloys in the form of powder causes excessive oxidation of the metal, a further disability being that non-uniform surface layers often contain unmelted particles of aluminium and other constituents. Light metal wires, 0·04-0·06 inch diameter, have given best results. The process is being used to a large extent in the manufacture of kitchen ranges, automobiles, motor cycles, household materials, etc.

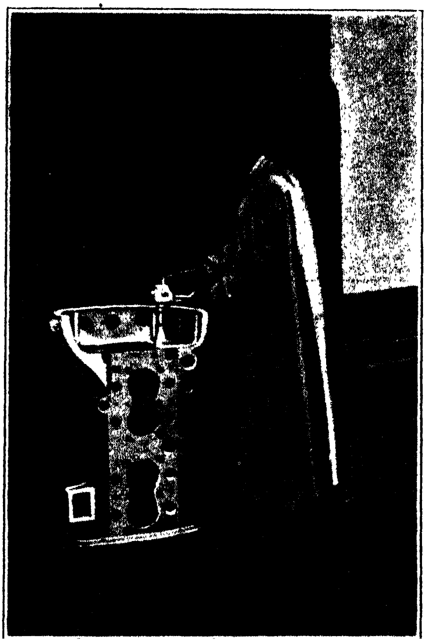

FIG. 180.—Repairing Defects in an Aluminium Casting by means of the Metal-spraying Pistol.

Chemical Industries.—The metal-spray process has already been applied to various branches of the chemical industry; numerous bleaching, electrochemical, dye, and explosive works have already had their manufacturing apparatus coated in this manner. The process here comes into consideration primarily for apparatus such as large containers, boilers and reservoirs, which are used for boiling, vaporising, evaporating, and storing, or for transportation of the finished products.

In chemical works, lead is generally the most valuable coating material, although other metals are also used for this purpose. In England, lead spraying has been carried out on a large scale, and special machines have

FIG. 181.—Lead-spraying the Inside of Large Iron Pipes for Chemical Work.

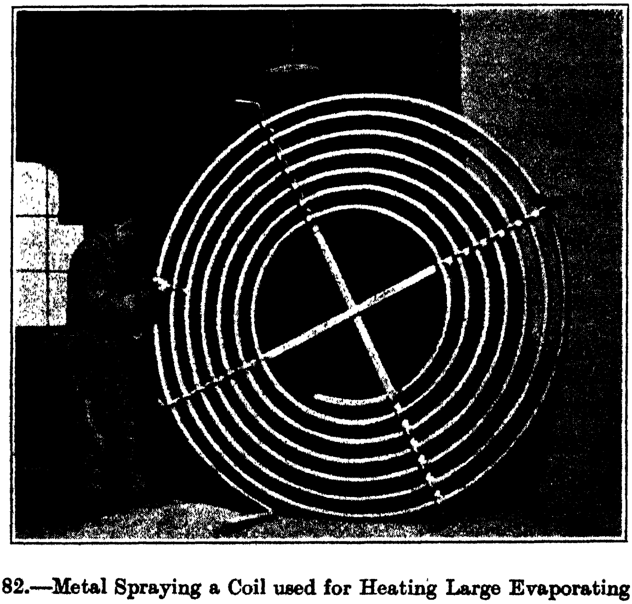

FIG. 182.—Metal Spraying a Coil used for Heating Large Evaporating Pans.

been developed to cope with routine work of this type. Where very thick coatings of lead are required "lead burning" may be the more practical method of applying the lead coating, but for all the usual thicknesses lead may be sprayed most successfully. In one works both methods are employed side by side. An example of this type of work may be seen in fig. 181, which shows how the process has been used effectively to lead-coat the inside surface of large riveted sheet-iron pipes. On the other hand, it has been used to protect various types of heating coils which are frequently employed for heating evaporating pans and other fluid containers. An example of this type of work is shown in fig. 182. The choice of the coating metal for such purposes is obviously of great importance, and the spraying works in this country now possess considerable data to guide them in the choice of the best coating material to meet any stated conditions of service.

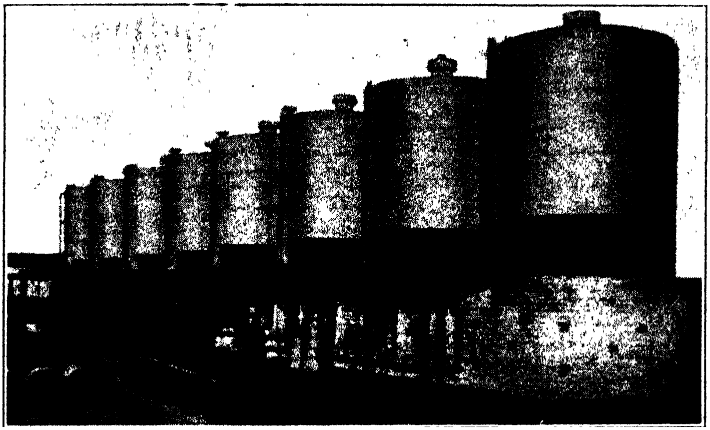

Fig. 183.—Storage Tanks protected by Metal Spraying.

The large pans used in chemical works are themselves frequently sprayed, thus permitting the use of stronger and cheaper metals for the mass of the tank while retaining the surface properties desired by spraying on a suitable metal coating. Storage tanks for chemicals are most subject to corrosion, and possibly the largest proportion of the spraying work carried out in this country recently has been upon such work. In particular, the process has been extensively used for coating the large petrol storage tanks used by the big distributors. Such steel tanks are rapidly corroded by impurities in the petrol; however, it has been found possible to greatly lengthen their life by metal spraying them with a protective surface layer. A battery of such tanks may be seen in fig. 183. Finally, one may mention that almost as much trouble is experienced with the transport of chemicals as with their storage. Fig. 184 illustrates how tank wagons have been treated in a similar manner to the storage tanks mentioned above. In the same way this process has already been used for filter presses, the coating of such articles as glass chemical apparatus, and a hundred and one other purposes connected with the great chemical industries. In America tank cars used for transporting high-grade glycerine are sprayed with zinc to prevent discoloration and contamination. Aluminium coatings have been applied to pressure vessels used in oil refining. To carry out this work it is advisable to

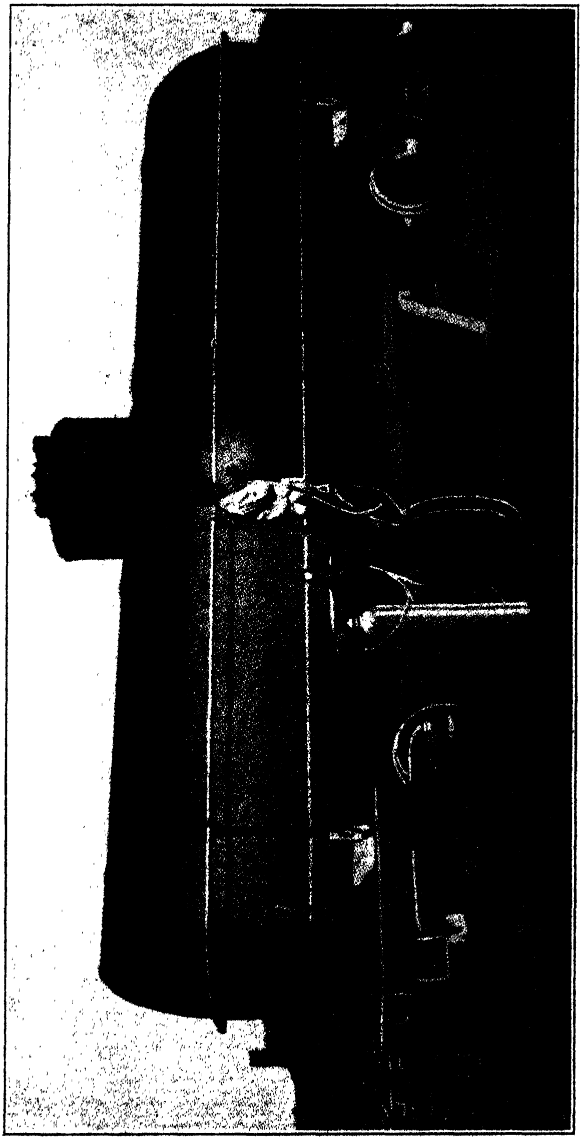

FIG. 184.—Tank Wagons for Transport of Chemicals or Oils have been Sprayed both Inside and Outside to Protect them from Corrosion.

clear the tank of trays and to fix a discharge fan at the top of the tank, so that sand does not pass through. A suitable draught should be 90 cu.ft./min. All connecting lines must be blanked off and any oil found in the seams must be removed by heating with a torch. Totally enclosed electric lamps should be used to obviate shorting by the fine metallic dust in the atmosphere.

For protecting the floating roof on a tank containing sour naphtha a 20/1000 inch coating of lead was fairly successful, but zinc and cadmium were rapidly attacked. Monel coatings (0·030 inch) were reasonably good in protecting steel pulp-washing pans against the attack of sodium hydroxide, sulphur and sulphur compounds. The coating of a food vessel with tin by means of an extension nozzle fitted to the pistol is shown in fig. 185.

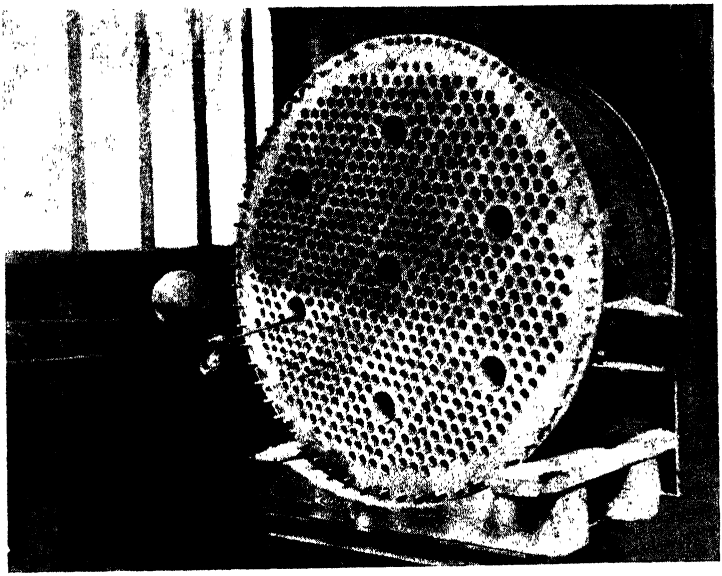

FIG. 185.—Spraying a Multitubular Food Vessel with Tin, using Rotary Extension Nozzle (Wire Process).

Rollers used in the manufacture of photographic films are frequently made of duralumin for lightness and coated with nickel to prevent chemical reactions occurring between the film and the aluminium. A somewhat similar application is cited by Daeschle* in which a porous metal cylinder, produced by an electrothermic process, needs only initial oiling, but has the disadvantage that in rotation oil is forced out into contact with a leather covering, which deteriorates. To obviate this, a sprayed-on metal covering is employed, forming a sealed surface and a good bond for the leather.

Foodstuffs and Breweries.—In the modern large foodstuff manufacturing works and in modern breweries the plant employed is seldom painted;

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* *Metallizer*, 1934, 3, 3.

bare metals and metallic coatings, predominant for reasons of cleanliness, are imposed upon such industries by the present-day sense of hygiene.

Iron, being soluble in many vegetable acids, cannot be used unless coated with some other metal, and such coating has not been always easy or satisfactory. On the other hand, massive boilers and vats made from solid aluminium or copper are most costly. For many purposes, therefore, it has been found that iron vessels sprayed with aluminium or tin suit the conditions imposed by such work.

In one large factory, many milk separator castings of considerable dimensions have been sprayed internally with tin. Thicker coatings of aluminium are replacing tin for this purpose. For boilers which require violent stirring, solid metal is naturally to be preferred, but for many other vessels used in the foodstuffs industries the metal-spray process has proved a great assistance. Fig. 186 shows an example of this, a battery of centrifuges externally sprayed with aluminium. This coating of aluminium prevents corrosion of the exterior, looks clean, and aids general cleanliness by reflecting light very well. Such coatings of aluminium do not peel off in the ready manner unfortunately observed too often with aluminium paints, and may be cleaned very easily by rubbing with a wire scratch brush. The interior parts of such centrifuges have in some cases been sprayed with tin. Coatings of about 10/1000 inch thickness are common.

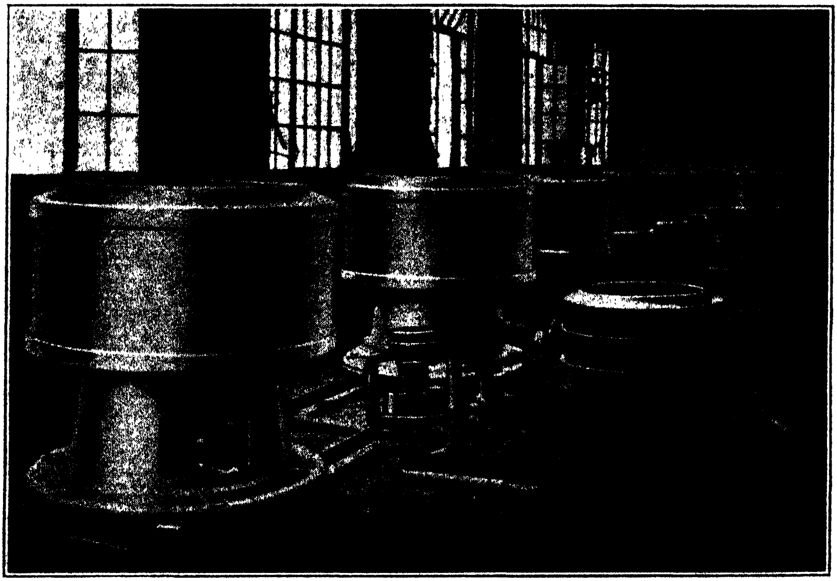

FIG. 186.—Centrifuges Sprayed Externally with Aluminium and Internally with Tin.

Copper was used almost exclusively for fermenting vats, but it has been stated that this metal has the effect of retarding the action of fermentation. In certain cases, therefore, copper vats have been sprayed with tin, as in the plant shown in fig. 187. Highly polished tin coatings are used on jelly moulds and these have the advantage that there is a good heat transference, which was not obtained with similar moulds lined with sheet tin. Tin coatings are also applied to bronze rollers which have to be coated with rubber.

Silver has been sprayed upon parts of foodstuff plant, but tin has been most generally used for this purpose in the condensed milk, chocolate, margarine, meat-extract, preserved fruit, and other industries of this type.

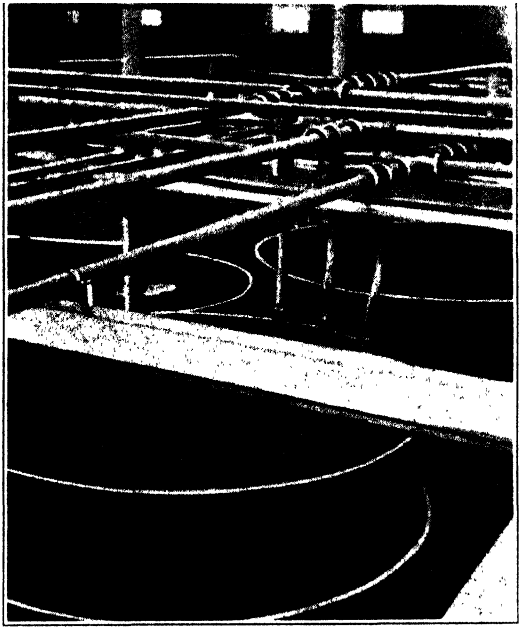

FIG. 187.—Copper Fermentation Tanks sprayed with Tin.

Electrical Industries.—The metal-spray process has been used for many purposes connected with the electrical industries, of which a few typical examples will now be mentioned.

Heating elements have been produced by spraying spiral or zigzag strips of metal, the formation of which was guided by suitable stencils, upon the usual refractory foundation. These have been manufactured as portable or stationary resistance heaters for dwelling rooms, but the same principle might equally well be applied to the actual walls of such rooms as bathrooms. The inventor has indeed suggested the spraying of a suitable pattern upon a wall; the metal strip so produced to be used as a resistance heater.

Another somewhat unexpected use of the process has been developed abroad, and appears to deserve greater attention from electrical engineers in this country.

During the War, when copper was scarce in Germany, the copper bonds were removed from certain electric railways and electrical connection between the two rails was secured by sand blasting the rail ends *in situ* and spraying them with zinc. Inside surfaces of the fish-plates were similarly treated. So successful was this substitution for the usual copper bonds that one may now see miles of rail so treated in Berlin, Hamburg, Switzerland, and elsewhere. The experimental work which led to its introduction was described by W. Wechmann in a lecture reported in *Glasers Annalen*, 1916, **78**, pp. 113-128, and entitled "Ersatz kupferner Schienenverbinder auf elektrischen Bahnen," pp. 121-123. The diagram which is here reproduced in fig. 188 illustrates the results of these experiments, which lasted over a period including October, November, and December.

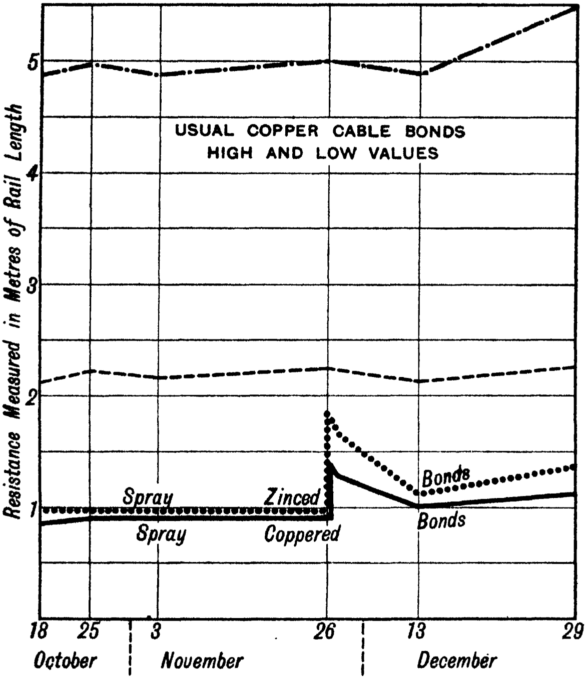

FIG. 188.—Resistance of Metal-sprayed Rail Bonds. (Wechmann.)

It will be seen from these that the resistance of the copper bonds was in all cases about twice that of the zinced fish-plates. Experiments were made with bonds in which the rail end and fish-plates were sprayed with both zinc and copper. It will be seen, however, that the improvement over the bond sprayed with zinc alone is relatively negligible. About half-way through the time of these experiments the fish-plates of the experimental bonds were taken off and allowed to lie in the open for some minutes, and were then fixed temporarily with only two bolts, and the resistance was determined before the train had passed.

From the diagram it will be seen that this caused a considerable increase in the resistance, which was still, however, less than that of the best copper bond, and that after putting in the other two bolts the resistance was again lowered, and after a few days regained the original low value. Apparently the shaking caused by the train passing over it effected a more intimate fitting together of the fish-plate and rail-end surfaces. The alteration of the resistance with time, which is to be noted in all of the bonds examined, was due to the different moisture of the earth, which, of course, takes part more or less in conducting the return current.

The cost of zincing the rail ends as described came to less than the pre-War cost of installing the same number of copper wire connections.

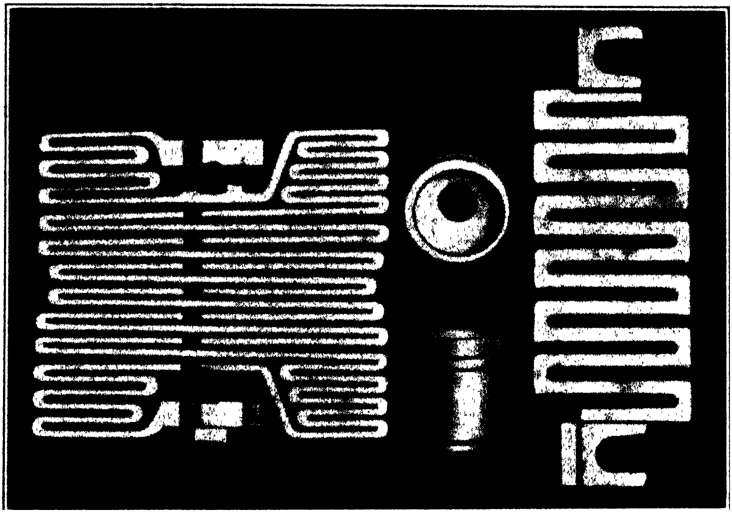

Fig. 189.—Tramway Motor Resistance Grids sprayed with Zinc.

The better electrical properties, economy, and greater flexibility of this type of rail bond make it worthy of more serious consideration in this country than it has received up to the present. It should be noted that it is not necessary to spray with zinc the whole length of the rail, and, furthermore, that the cost of installing this type of bond would probably be still further reduced were the zinc spraying, etc., carried out in some fixed shop before the rails were laid, as the portable plant which was used in the experiments described cannot operate so economically as a well-organised stationary plant. In February 1925 the spray-zinced bonds were still giving every satisfaction and regarded as far superior to any other type. On the other hand, the resistivity of thinly-sprayed copper is about eight times that of the solid metal.

The metal-spray process has also been used to cover cast-iron resistance grids such as are used in connection with tramway and other motors. If such grids are zinced as shown in fig. 189, the value of the composite resistance is not altered by the formation of corrosion products at the many joints.

In much the same manner small transformer casings have been zinc-sprayed, as shown in fig. 190. Where such transformers are arranged in outdoor stations the need for protective coatings is still greater, and a considerable amount of spraying work has been performed upon overland transmission masts and outdoor transformer stations, as illustrated in fig. 191, which is typical of many similar plants which have been sprayed with zinc.

Metallised radio valves are now well known, and fig. 192 shows a machine which carries out the actual metallising of the valves automatically. In this case gelatine is first applied to the glass, forming a bond for the subsequent zinc coating. Copper is also sprayed. In radio sets it is necessary to provide earthed metallic screening between the various parts, which can be done by the use of a metal chassis. This is expensive and not so suitable for kit sets sold for home assembly, and the difficulty has been overcome by the use of wooden chassis sprayed with zinc by the molten metal process. All components can be automatically earthed, and wires can be soldered to the chassis without the use of metal working tools, which home constructors do not like to use. Sprayed coatings are used also for X-ray screening.

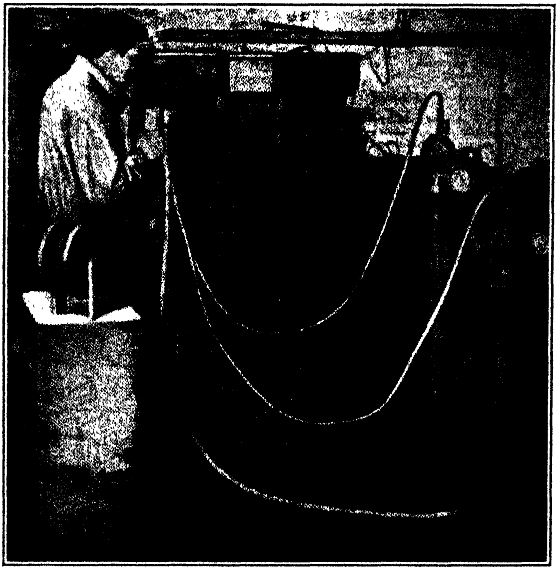

FIG. 190.—Zinc-spraying a Transformer Casing.

The suppression of interference caused by electrical apparatus used for diathermy, ultra-violet ray treatment, etc., presents unusual difficulties due to the fact that the patient undergoing treatment radiates high frequency energy from his body. It is necessary to provide a complete electrostatic screen enclosing patient and apparatus and to connect a filter in the supply mains. In the case of a violet-ray set, it is recommended that the screening cubicle be constructed by stretching half-inch wire netting over a wooden framework, and this is the method adopted at the present time for screening.

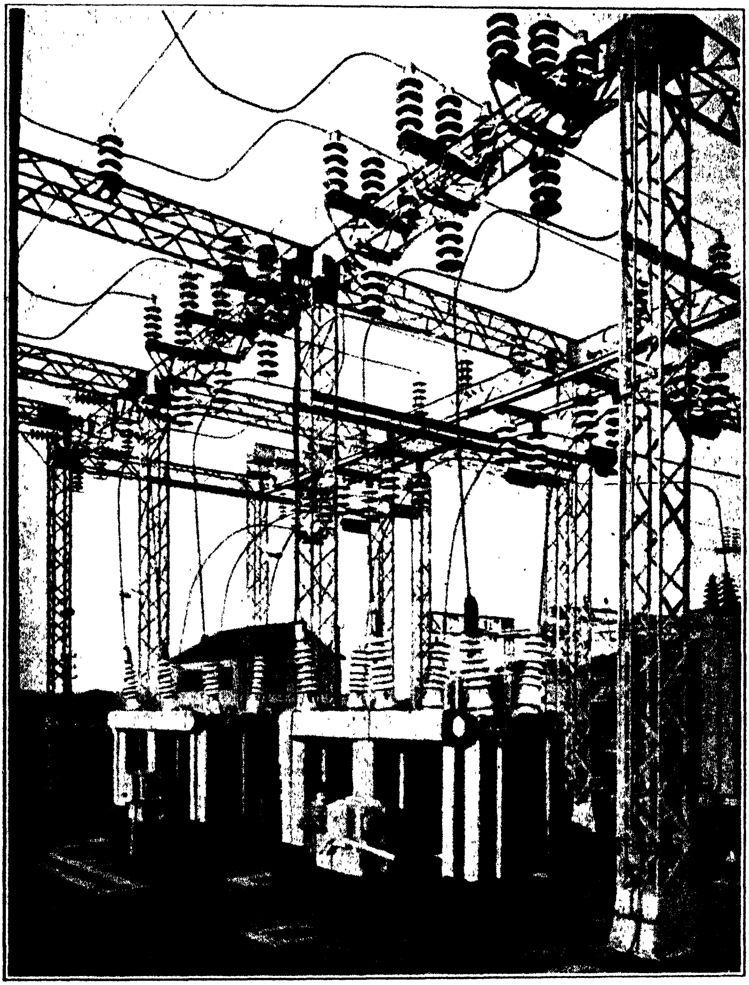

FIG. 191.—Outdoor Electrical Plant sprayed with Zinc.

It has been found, however, that as an alternative, the walls, ceiling and floor of a room can be screened by spraying with zinc. In spite of the extremely thin metallic coating, it has been proved that the screening by this means is better than that obtained by wire mesh.

Another novel use of metal spraying is in the treatment of bandages for use in diathermy. This replaces lead discs, which do not make such good contact with the patient's flesh as the sprayed bandage, and burning is obviated.

Large plaster casts have been zinc-coated to form a voltage measurement condenser in connection with a 300 K.V.A. testing transformer.

The process has so many possibilities for electrical engineering concerns, other than the obvious corrosion proofing uses, that certain of the leading electrical concerns have taken to metal spraying in their own works as licensees.

Heat Treatment and Furnaces.—The prevention of oxidation at high temperature is almost as important as the prevention of ordinary corrosion. Furnace doors and door-posts are short-lived, and carburising and annealing boxes rapidly scale away in service.

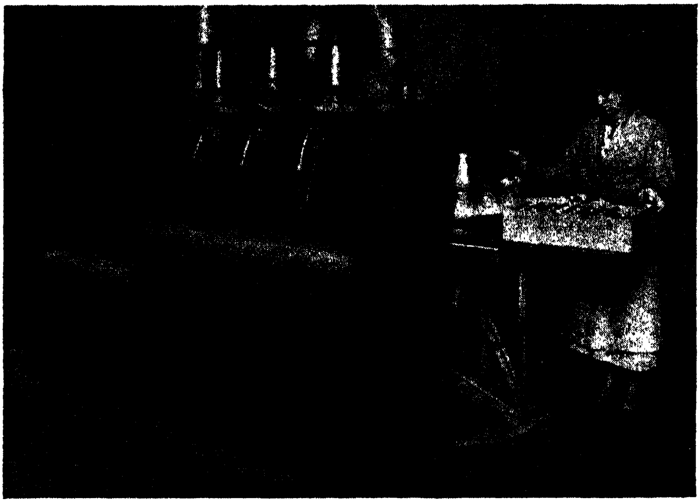

FIG. 192.—Spraying Radio Valves, for Metallic Screening.

The metal-spray process has been used to protect such parts, and will probably be more extensively so used in the future. Aluminium is generally sprayed for this purpose, but nickel alloys may be applied if desired.

Experiments have shown that copper sprayed with aluminium and suitably heat-treated possesses exceptional powers of resisting "scaling" or progressive oxidation at high temperatures. The surface of articles so treated turns yellow owing to the formation of an alloy.

A large number of low-temperature furnaces have been constructed for use up to 550° C. with an inner lining of steel which has been sprayed with aluminium. Fig. 193 shows a cylindrical furnace approximately 31 feet long for tempering work at temperatures up to 550° C., which has been constructed in this manner. This particular furnace has an inner baffle, which is provided to allow a path for the circulation of the furnace atmosphere by means of a fan mounted in the back of the furnace. Certain bright annealing furnaces comprise a cylindrical bell which is dropped over the base carrying the charge, the base itself being of metal-sprayed steel and the charge cover of steel, metal-sprayed and heat-treated. Large tanks used for salt-baths are also aluminised. Many firms find it difficult to give figures for the life of aluminised and untreated parts owing to the fact that they have not constructed any two jobs where the working conditions are in any way similar, and where one is provided with ordinary mild steel parts and the other with aluminised parts. Generally speaking, aluminised parts would not be used above 750° C., as, although they would resist oxidation up to 900° C., they would not have sufficient strength at high temperatures. It is for this reason that, above temperatures of 750° C., nickel-chrome alloys are used.

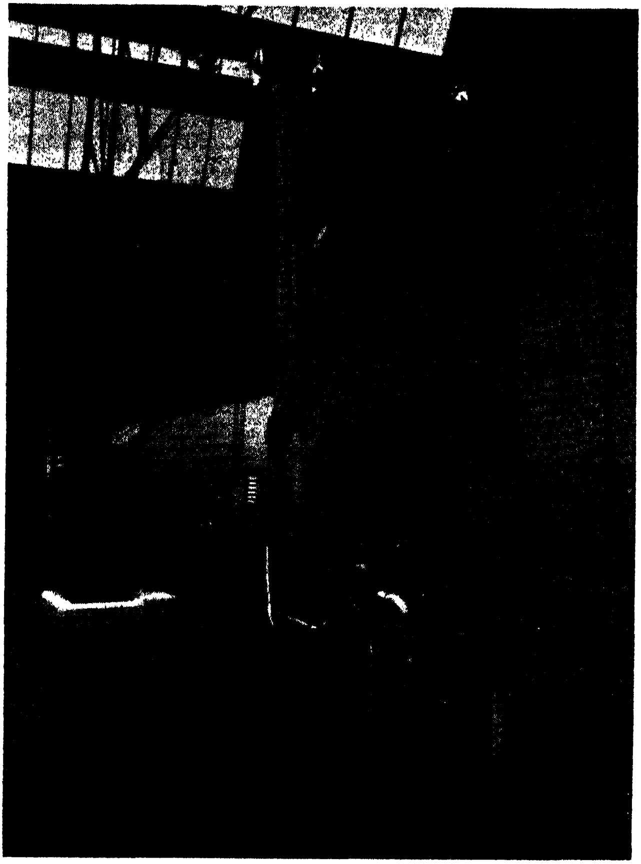

FIG. 193.—Air Furnace, with Aluminium-coated Liners.

Further, if the parts are subject to any wear or abrasion, a metal coating is useless. Metallised containers in bright annealing furnaces have another advantage over ordinary steel parts; namely, after heating the container beneath the furnace bell, the latter is removed, and the container then sprayed with water: this water spraying would cause very bad rusting on an untreated surface.

Most grades of cast-iron grow under the influence of prolonged heat and as the aluminium oxide skin cannot grow at the same rate, a crazed effect is obtained and oxidation proceeds along the lines where the aluminium oxide skin has fractured. An iron not subject to growth is advisable and, of course, several irons made to resist growth have also a high resistance to oxidation, so that aluminising may not be necessary.

Surfaces impregnated with aluminium also resist the attack of sulphurous gases extremely well and surfaces formed by spraying nickel-bearing alloys with aluminium prevent sulphurising.

Aluminising is specified for aircraft manifolds by the Air Ministry.

A neat application of the process, though one of less general interest, is the preparation of protective coatings on machine parts and other articles which have to be case-hardened in particular regions, while retaining their normal condition in the remaining parts.

In order that such protective coatings should satisfy the demands of practice, they must:—

1. Resist the temperature at which case-hardening is carried out, since otherwise they would melt either partially or entirely.
2. Be impervious to the materials which effect the hardening.
3. Be manufactured quickly and easily in satisfactory thickness, and, after hardening and tempering, be easily removed if necessary.

The second condition is fulfilled by all metals, the first and third by a few, of which in practice only copper and nickel are suitable; since nickel, however, is very expensive, it is also excluded, so that only copper coatings come into consideration.

The most simple process of obtaining such copper coatings consists in dipping the article in copper salt solutions or in painting the particular place with such solutions. The copper layers obtained in this manner are, however, under the most favourable conditions, much too thin to protect effectively during the long time of the hardening process. Further, such layers possess quite an irregular structure, and since they really only adhere firmly in places, they can easily peel off. These conditions make such coatings in general almost valueless. Electrolytically deposited coatings naturally satisfy all demands with respect to adhesion, thickness and so on, but the electrolytic process is cumbersome and takes a considerable length of time.

These defects caused Guillet to investigate the metal-spray process for its suitability for preparing the coatings in question. The investigations showed that spraying for a few minutes was enough to produce a copper coat which offered undoubted protection against the hardening gases, and, as an especial advantage, he upholds the great simplicity of the process.

Further investigations in the same direction have been made by N. P. Nicolardot, who dealt fairly fully with the question in "Les Progrès dans la Métallisation à froid."* Coating with clay for the demarcation of carburisation is unsatisfactory because cracks form and the carbon diffuses in, giving ill-defined separation of the parts to be carburised.

The porosity in sprayed copper is a disadvantage in this application and Slater (in a private communication) showed that the protective character of the coating is not always uniform. The sprayed copper did not prevent carburising entirely, but retarded the rate of penetration considerably.

Waterproofing of Wood.—Another application where porosity is a serious drawback is in the spraying of wood in India to prevent changes in its moisture content and dimensions. Experiments were carried out at the Forest Research Institute, Dehra Dun, India, to find out to what extent wood sprayed with metal is protected against changes in its moisture content and dimensions. A report of this work was given in the *Indian Forester*. For the purpose of the tests, air-seasoned planks of teak, haldu sissoo, Indian rosewood, gurjan and andaman were taken and cross-cut to give four specimens. Certain control pieces were also procured. The specimens were sprayed with various metals by Messrs. Allen-Liversidge (India), Limited, of Bombay.

After a few days of air-conditioning, all of the specimens were put in a chamber maintained at a temperature of 95° F. and a relative humidity of 72 per cent., in which they were allowed to attain a state of equilibrium by remaining therein for about a month. Weights and measurements before and after this treatment were recorded. Then the specimens were transferred in succession to vessels kept at 53, 30, 50 and 90 per cent. relative humidity, respectively, to determine the effects under this series of different conditions. Following this, they were transferred from the 90 per cent. relative humidity chamber to one at 30 per cent., and weighed and measured daily, to find the amount of retardation in the rates of moisture loss and of shrinkage, as compared with the untreated controls. Further tests were made to discover the absorption of water under a spray, as well as by soaking for eight days.

The results proved to be very interesting. It was found, for example, that metals of low melting-point, such as tin, lead and zinc, when sprayed on wood, reduced its susceptibility to changes in moisture content and dimensions due to variations in the humidity of the atmosphere by from about one-half to one-third. In contrast to this, it was found that metals melting at higher temperatures, like bronze, brass, copper and aluminium, do not protect wood appreciably against changes in the atmospheric humidity. It was also noted that sprayed metal coatings do not protect wood against absorption of water during soaking. Indeed, the amount of water absorbed was increased in most cases. Frequent swelling and shrinkage of the wood can, and does, weaken the bond between the metal film and the wood surface, and causes cracking, and later peeling off, of the metal.

Building-up Work.—The development of the use of the metal spraying process for the application of deposits to wearing surfaces is comparatively recent, but the process is now used to a considerable extent for this purpose.

Until the advent of metal spraying into this field, the coating of worn steel machinery parts for the purpose of bringing them back to the original size was catered for by two processes, namely welding and electrodeposition.

Welding is the best method of applying very heavy deposits of metal,

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* *Bull. de la Soc. Indust. de Rouen*, March, 1914.

but has the disadvantage that, owing to the heat developed during the process, great care must be taken to avoid distortion. This is usually done by pre-heating the work, but such is not always possible nor is it always desirable.

Electrodeposition for the building-up of worn machinery parts is carried out with nickel or chromium and highly adherent deposits are produced. This process is particularly useful for applying comparatively thin deposits, but is slow for the building-up of heavy coatings. The size of articles which can be treated is limited by the size of plating bath available.

Until the last few years, operators of the metal spraying process were chary of advancing the use of sprayed coatings of iron and steel for wearing surfaces, firstly because of the uncertainty of their behaviour under stress, and secondly because of the difficulty in obtaining good adhesion of heavy deposits with hard metals. The difficulty of obtaining good adhesion of sprayed metal deposits of iron, steel, etc. was overcome in respect of the coating of shafts and cylindrical surfaces which can be machined in a lathe, by cutting a rough screw thread on the article before spraying. The surface is cut 20-30 threads per inch, the actual number of V threads depending on the diameter of the shaft—the smaller the diameter of the shaft the greater the number of threads. During the cutting of the threads the tool, having no rake, is so set that in addition to cutting it also has a tearing action, which produces jagged prongs or barbs on the threaded faces. Pieces clinging to the top of the thread can be removed by a tool ground flat on the end and run in on the traverse until it just misses the top of the threads. Before the roughening process is carried out it is advisable to machine down (0·04-0·05 in.) the part being treated so that, even with the maximum amount of wear likely to occur on the shaft, the actual bond between the base and the sprayed metal will never itself be subjected to frictional wear, which might be likely to tear away particles of sprayed metal from the base. The shoulder at the end of the undercut part is then dovetailed to form a key for the deposit.

The protection of parts adjacent to the prepared surface can be carried out by binding with insulating tape, or by the application of a thin film of blacklead. Keyways should be filled in at this stage by the admission of the keys smeared with blacklead.

It should be remembered that any power being transmitted by the key will be partly carried by the deposit, so that it would not be advisable to put a shaft into service after building-up by metallisation in such a way that a large part of the load was being transmitted through the deposits. Such loads produce a shearing force on the bond at its weakest place. In doubtful cases it is advisable to calculate whether the remaining thrust face of the keyway is sufficient to carry the total load, ignoring the deposit. If this is so, then the deposit should be cut away to be clear of the key.

This type of preparation can be used for all kinds of shafts, hydraulic rams, rolls, journals, etc., but is not recommended where heavy vibratory stresses occur and fatigue cracking is likely to be set up, *e.g.* it is not considered advisable to screw-cut the bearings of crankshafts, as the risk of fatigue cracking would be increased by the removal of the smooth skin from the stressed member. In cases where fatigue strength is important, rough turning should be done with a round-nosed tool, followed by sand blasting. This treatment prevents lateral movement. Sand blasting also has to be used for certain alloy steels, which show a polished surface after cutting.

The building-up of internal bores is more difficult than shafts owing to the tendency of the metal deposit when cooling to contract away from the bore. It is essential, therefore, to avoid the effect of the contraction by ensuring that the temperature of the part being treated is increased as little as possible, or by spraying small areas at a time. The building-up of a cylinder bore with high carbon steel is much more common in America than in Europe.

The metals and alloys used for coating worn machinery parts will vary according to the base metal and the service which they are expected to withstand. For coating mild steel shafts, etc., a mild steel (0·25 per cent. C) is generally employed, and it should be applied in one traverse of the pistol to avoid oxide layers. The work should be kept cool. Machining to the correct size can be carried out after spraying and a machining allowance of not less than 0·015 inch is necessary. A Wimet **N**-tipped tool has been found to be very suitable for cutting sprayed steel when a very sharp tool, with cutting edge 90° to the job and $\frac{1}{64}$ inch above centre, is used at a speed of 75 ft. per minute, 336 cuts per inch and a maximum cut not exceeding 0·001 inch. For sprayed bronze a similar tool yields a satisfactory machined surface when the speed is 350 ft. per minute, 336 cuts per inch and the maximum depth of cut 0·002 inch.

Where a hard wearing surface is required, a steel with a higher carbon content (0·75 to 0·9 per cent.) is used, but the deposits from these steels are too hard to machine and grinding must be resorted to. The grinding of all sprayed metal coatings should be done wet with as large a wheel as possible, at a surface speed of 6,000 feet per minute, and work speed 160 r.p.m. for a 2 inch diameter shaft.

Conditions causing corrosion and frictional wear can frequently be overcome successfully by the use of deposits of nickel or stainless steel, *e.g.* hydraulic rams and pump shafts may be built-up with this metal or alloy. The stainless steel wire should be of the " decay-proof " type.

Bronze and brass propeller shafts can be coated with any alloy of approximately the same composition.

Hard metal deposits are sometimes applied to soft metals to give the surface better resistance to wear, *e.g.* rolls made of duralumin for strength and lightness have been given a coating of nickel.

Two cases may be cited of the value of this new method of repairing worn machinery parts. In both cases it would have been impossible to carry out the repair by any other method.

(1) Owing to wear, the roller bearing housings on four chilled iron rollers used in a brass rolling mill were turning on the journals. The replacement of the rollers would have been expensive and entailed much delay as the mill was of Continental design and the rolls could only be supplied by the manufacturers of the mill. The journals were prepared, sprayed and finished ready for the ballrace housings to be fitted in three days.

(2) A similar instance occurred with two large rollers for a paper mill. The four journals were machined and built-up by spraying, machined to size and ballraces put in position in 28 hours, between midnight Saturday and 4 a.m. Monday, without interfering with the normal production of the mill.

The above instances of work upon which satisfactory reports have been received after long periods of service, give an indication of the value of this method of repairing.

Paper and Fabrics.—The metal-spray process is already employed in several factories for coating embossed or moulded paper, cardboard, or papier-mâché goods. A manufacturing firm at Frankfurt is utilising the process of metal spraying in connection with the production of cartons made from specially prepared and hardened paper cylinders. The cartons are metal sprayed when finished, and the containers are thus obtained with a capacity up to twenty gallons, or barrels, if hoop bound, containing seventy gallons. Many of these receptacles are sold to the dyeworks at Höchst to be used for containing dyes, and others are supplied to manufacturers of chemicals, margarine, soap, foodstuffs, and other articles. One application of the spraying of paper or fabric which appears to deserve attention is the spraying of surfaces with tin, aluminium, or other white metal in the manufacture of projection screens for cinematograph purposes. The usual matte surface produced in metal spraying is very suitable for this purpose so long as it is not made from a metal which oxidises readily or otherwise loses its brilliance. Screens of this type have been made upon cardboard, papier-mâché, linen, and even glass.

As regards the metal spraying of fabrics, a number of quite striking results can be produced by spraying different coloured metals on to fabrics over which suitable stencils have been placed. There is apparently no reason why metal-sprayed fabrics or lace should not become articles of commerce, but success in this direction will depend more upon taste and fashion than upon technical considerations.

It has been stated that the process has been used for aluminium spraying airship fabrics; it is difficult to obtain information as to the extent to which this has been carried out. The spraying with metal of a balloon fabric carries with it the advantage that the surface is made conducting as well as weatherproof; the danger of the balloon being set on fire electrostatically is thus somewhat reduced. While on the subject of aircraft, it may be mentioned also that aeroplane propellers are said to have been sprayed both in Germany and in Switzerland on a fairly extensive scale.

Artistic Work.—The process obviously lends itself to many uses of a more or less decorative or artistic character. Posters, signs, headstones, and name plates have all been produced in various materials with the aid of the metal-spray process. A name plate can be manufactured out of a sheet of plate glass as follows:

A stencil formed as required from a piece of gummed paper is stuck to the glass, which is then sand blasted to produce the desired amount of relief. The stencil is removed, the whole of the glass plate lightly sand blasted, and the surface then sprayed all over with any metal as desired. In some cases the letters are then polished, while the remainder of the name plate is allowed to remain matte. The process has been used for many kinds of decorative work of this type, and many shop fronts and exhibition stands, while appearing to be of solid metal, have in recent years been manufactured from wood and plaster or other non-metallic materials, and metal-sprayed on the surface.

It is possible to use the spraying process in the same manner as electrotyping; that is to say, to produce facsimiles of moulded articles. An example of the type of work produced by spraying upon a negative mould is illustrated in fig. 194.

Many other uses for the process of a like character exist, but it is impossible to mention them in the present book. One concluding example does, however, deserve reference, and that is the use of the process for imitating massive metal articles.

Plaster-casts taken from valuable artistic articles have been used to manufacture imitations of the original by means of this process. Without any sand blasting or other preparation, the plaster is sprayed with a strong surface layer of metal which may be polished or given a patina as required, in order faithfully to reproduce the original. The same process is used commercially to manufacture imitation bronze or other metal articles.

FIG. 194.—Plaque Produced as a Separate Article by Metal Spraying a Separable Layer upon a Negative Mould.

Quite striking results have been produced by metal-spraying photographic negatives and prints, and it is understood that this application has been also developed commercially abroad.

The doors installed at Imperial Chemical House, London, which are 20 feet in height by 10 feet in width, have been faced back and front with Silveroid by metal spraying. The panels illustrate the evolution of modern society and the progression made by man from primitive conditions through the application of science to industry.

According to the *Metallizer* (Nov., 1934) a concrete monument in Griffiths Park, overlooking Los Angeles, was sprayed with three undercoats of lead to stop leaching of the concrete and to give a better bond for the copper. Four coats of copper were applied with the pistol at eight inches distance from the surface to prevent blistering the lead. The copper was oxidised with a solution of 4 oz. of liver of sulphur to 1 gallon of water and a coating of outside clear varnish was then applied.

In concluding this brief survey of the applications of the metal-spray process one must make it clear that the most important uses of this interesting process have been, undoubtedly, those connected with the protection of comparatively large constructions or works' apparatus against the ravages of corrosion and oxidation at high temperatures.

The process merits wider use by engineers, and it is hoped sincerely that this account of its nature and possibilities will encourage designers to use metal spraying for the protection of many of their constructions.

APPENDIX.

REFERENCES TO THE METAL SPRAYING PROCESS.

The following references are appended in acknowledgment of the sources of information consulted by the authors, and in the hope that they may assist readers who desire to pursue the subject in greater detail.

The Bibliography published below is in the main that prepared for the papers by Turner and Ballard in 1924 and Rollason in 1937, both of which omitted reference to abstracts and obvious reprints.

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INDEX OF NAMES.

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